



COMMITTEE OF THE PRIVY COUNCIL FOR
AGRICULTURAL RESEARCH

REPORT OF THE
AGRICULTURAL RESEARCH COUNCIL
FOR THE YEAR 1958-59

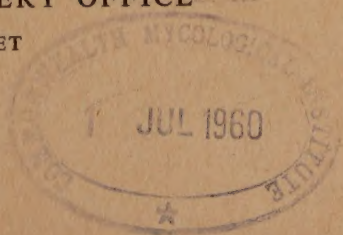
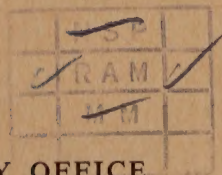
*Presented to Parliament by the Minister for Science
by Command of Her Majesty
June 1960*

LONDON

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AGRICULTURAL RESEARCH COUNCIL

At Date of Report

His Grace The Duke of Northumberland, K.G. (Chairman)
David Lowe, Esq., C.B.E. (Deputy Chairman)
J. D. Alston, Esq., J.P.
Professor T. A. Bennet-Clark, M.A., Ph.D., F.R.S.
Professor F. W. Rogers Brambell, B.A., D.Sc., Ph.D., F.R.S.
H. G. Button, Esq., B.A.
Professor E. G. Cox, T.D., D.Sc., F.Inst.P., F.R.I.C., F.R.S.
R. E. Glover, Esq., M.A., D.Sc., F.R.C.V.S.
Professor J. W. Howie, M.D., M.R.C.P., F.R.F.P.S.
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Professor K. Mather, C.B.E., D.Sc., Ph.D., F.R.S.
Professor P. B. Medawar, C.B.E., M.A., D.Sc., F.L.S., F.R.S.
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Professor S. J. Watson, C.B.E., D.Sc., F.R.I.C., F.R.S.E.
Sir William K. Slater, K.B.E., D.Sc., F.R.I.C., F.R.S. (Secretary)
W. G. Alexander, Esq., C.B.E., M.A. (Deputy Secretary)

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Sir William K. Slater, K.B.E., D.Sc., F.R.I.C., F.R.S.

Deputy Secretary:

W. G. Alexander, C.B.E., M.A.

Assistant Secretaries:

E. D. T. Jourdain, B.A.

W. Ness, C.B.E.

P. A. C. Thorne

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E. E. Cheesman, D.Sc., A.R.C.S.

G. G. Samuel, M.Sc.

R. Scarisbrick, M.A., Ph.D., M.R.C.V.S., A.R.I.C.

F. H. Moulton, M.Sc.

D. Rudd Jones, M.A., Ph.D.

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THE REPORT OF THE COMMITTEE OF PRIVY COUNCIL FOR AGRICULTURAL RESEARCH FOR THE YEAR 1958-59

TO THE QUEEN'S MOST EXCELLENT MAJESTY,

MAY IT PLEASE YOUR MAJESTY,

We, the Lords of the Committee for Agricultural Research of Your Majesty's Privy Council, humbly submit to Your Majesty a Report of our proceedings during the year from 1st April, 1958 to 31st March, 1959.

During the financial year 1958-59, Parliament provided a total of £4,196,000 as a grant-in-aid of the Agricultural Research Fund. This total was based on estimated current expenditure of £3,973,300 gross, receipts of £272,000 and capital expenditure of £494,700 on buildings and special equipment.

The estimates of the Agricultural Research Council for that financial year were met by our provisional allocation of funds under the following heads :

- For administration, including the expenses of the Council and the administrative offices and staff ;

- For the current expenditure, including salaries and wages of the staffs, of the Council's Institutes and Units ;

- For grants for current expenditure, including salaries and wages, to State-aided research institutes in England and Wales ;

- For grants for special research schemes ;

- For Training Awards, Fellowships and visits abroad ;

- For capital expenditure, mainly on new buildings for the Council's research institutes and Units and for the State-aided research institutes.

As reported last year, His Grace the Duke of Northumberland, K.G., succeeded the Lord Rothschild, G.M., M.A., Sc.D., Ph.D., F.L.S., F.R.S. as Chairman of the Council on the 1st July, 1958. The only other change in membership of the Council during the period under review was the appointment of Mr. W. H. Senior, F.R.S.E. in place of Mr. L. G. Davidson, C.B. (who retired from Government Service), as representative on the Council of the Department of Agriculture for Scotland.

On the 30th October, 1959, Your Majesty was pleased to appoint a Minister for Science and to direct by Order in Council that the Minister for Science should succeed the Lord President of the Council as the Chairman of the Committee for Agricultural Research of Your Majesty's Privy Council.

We now beg to submit the Report which we have received from the Agricultural Research Council describing the progress of its work during the twelve months ending on the 31st March, 1959.

The programme for the post-war expansion of agricultural research, which was approved by the Cabinet in 1946, is now virtually completed. The only large projects outstanding are the provision of a permanent headquarters building in Edinburgh for the Animal Breeding Research Organisation and a farm for experimental work on the breeding of beef cattle. The latter development is being considered in relation to the Council's newly-assumed responsibility for food research, and in particular to the proposed laboratory for meat research.

Further expansion unforeseen in 1946 has been necessitated by the assumption by the Council of responsibility for the monitoring of radioactive fallout in agricultural products and the study of the way in which these radioactive substances move through the food chain and enter the different items in the nation's diet. Research work on farm buildings remitted to the Council in 1957 will also involve additional expenditure, although, under the recently announced scheme of grants for experimental buildings (which was suggested by the Council in the year under review), most of this expenditure should result in buildings of permanent value on commercial farms.

Although the Council has no formal responsibility for work outside the United Kingdom, it has through its headquarters staff and the staffs of the research institutes given much advice and help to those countries in the Commonwealth where technical help is needed. Scientists with special knowledge have been lent both for short visits to advise and for longer periods to fill essential gaps in the staff of research institutes. In a time of great political changes, the Council as an independent body of high scientific status has become a natural focus for scientists engaged in agricultural research throughout the territories which have, or are about to, become self-governing.

The Council, together with the Agricultural Improvement Councils for England and Wales and for Scotland, has been continuing its detailed study of the technical problems arising in the different branches of agriculture, in order to ensure that none of major importance is overlooked. Similar arrangements are now being made for the identification of the important problems of the food industries.

On behalf of the Lords of the Committee for Agricultural Research of Your Majesty's Privy Council.

HAILSHAM,
Minister for Science.

W. K. SLATER,
*Secretary to the Committee of Privy Council for
Agricultural Research.*

1st June, 1960.

THE REPORT OF THE AGRICULTURAL RESEARCH COUNCIL FOR THE YEAR 1958-59

To the Lords of the Committee of Privy Council for Agricultural Research.

May it please your Lordships,

The Agricultural Research Council begs leave to submit the following Report upon its proceedings during the period from 1st April, 1958 to 31st March, 1959.

INTRODUCTION

FOOD RESEARCH

Although the Council did not assume responsibility for food research until 1st July, 1959, the future of this work was under active consideration throughout the year under review. The Sub-Committee of Council Members mentioned in Council's Report for 1957-58 has continued to examine in greater detail the problems arising from these new responsibilities and the additional facilities to be placed at the disposal of the Council to be used in their solution.

In deciding on the problems to be solved, the Council is anxious to build up for food research a similar relationship with the Ministry of Agriculture, Fisheries and Food and the Department of Agriculture for Scotland to that which has worked well in agriculture. To that end the Minister of Agriculture, Fisheries and Food and the Secretary of State for Scotland have recently set up a Food Research Advisory Committee to advise on food problems requiring investigation or research which should be undertaken with the aid of public funds and to make recommendations as to the priority to be accorded to such problems.

The additional research facilities taken over (on 1st July, 1959) consisted of the Low Temperature Research Station at Cambridge, the Ditton Laboratory at East Malling and the Pest Infestation Laboratory at Slough. The four Research Associations concerned with food, viz. British Baking Industries Research Association, Research Association of the British Flour Millers, British Food Manufacturing Industries Research Association, Fruit and Vegetable Canning and Quick Freezing Research Association, are not immediately involved. It has been agreed by the Department of Scientific and Industrial Research and the Council that these Associations should be given an opportunity to see the new arrangements in action before deciding whether to remain with the Department of Scientific and Industrial Research or to transfer to the Agricultural Research Council. They have therefore been given the option of changing their attachment within the next five years. Whether they elect to transfer or not, steps will be taken to maintain the closest possible relationship between them and the three research institutes coming under the administrative control of the Council.

The present programmes of these institutes are being considered in relation to the work they may be called on to undertake and the staff, equipment and accommodation available. Even at this early stage it is clear that a number of major policy decisions will have to be taken in the near future. The Low Temperature Research Station is housed in a building held on a ten-year lease from the University of Cambridge. When this was renewed in 1956, the University informed the Department of Scientific and Industrial Research that, because of the great pressure on the space available in the centre of Cambridge, it would not be possible to renew the lease after 1966 except on a year-to-year basis. It will therefore be necessary to find fresh accommodation for the staff employed in the Station. Whilst this makes a major upheaval inevitable, it provides at the same time an opportunity for any reorganisation which consideration may suggest as a better use of the scientific man-power. The provision of fresh accommodation for the Low Temperature Research Station must be closely linked with the proposal to establish a Meat Research Institute. The staff of the Station includes the largest group of workers in the U.K. engaged on research related to meat, and hence it must be to this group that the Council looks for at least the nucleus of the staff of the new Institute. A small start has already been made in the development of meat research in relation to the Low Temperature Research Station by obtaining cold room and some laboratory space adjoining an abattoir at Cherry Hinton, close to Cambridge. This, for the time being, will act as an outstation for the Low Temperature Research Station, providing facilities not previously available for handling whole carcasses and freshly slaughtered material. It will also make possible the recruitment and training of staff for a full-scale Meat Research Institute. The form and location of this Institute is still under consideration: there are many interests to be reconciled.

The Ditton Laboratory was set up originally to carry out the developmental research needed to put into practice on a commercial scale the findings of the Low Temperature Research Station on the storage of fruit, particularly during transport by sea. The laboratory for this purpose consisted of a single large chamber, corresponding in size to one section of a ship's hold, surrounded by the rooms needed to house the refrigerating machinery, a workshop, storage and handling space for large bulks of fruit and accommodation for the laboratory and ancillary staffs. When this development work had been satisfactorily completed the "ship's hold" as such was no longer needed and the future of the Station had to be considered afresh. A new demand for work on storage has arisen since the War due to the increased production of home-grown fruit. Many orchards of top fruit were planted in the late forties and early fifties and are now coming into full bearing; it is essential that the crop should be stored in good condition for a maximum period so that it can be marketed uniformly. The Ditton Laboratory has attempted to meet this demand. The building has been adapted to provide more laboratory space and smaller storage units for experimental purposes and the programme of work has been largely reorientated. Problems arising in the storage of potatoes have also been added to the Laboratory's programme. Major questions have, however, still to be settled, first as to the future scope

of the programme and then as to the consequential changes necessitated in accommodation and staffing. The task will not be easy and to do it thoroughly will take time ; it is important, however, that when decisions are taken, they should be such that the Laboratory may look forward to many years of stability and steady work on the basic problems of fruit storage.

The Pest Infestation Laboratory does not present such complex problems of organisation. Here the immediate consideration is to relieve overcrowding and to allow the present programme of work to expand by providing additional accommodation on the existing site at Slough. A decision to provide a new building had already been taken by the Department of Scientific and Industrial Research before the transfer to the Council and this will go ahead as arranged without any break.

The importance has been previously stressed of considering the production, handling, storage, packaging and processing of food as links in one continuous chain of operations, the final objective of which is to provide the nation with food of the highest quality at the lowest economic price. The Council has therefore always in mind the need to integrate research on production with that on the intermediate steps involved in the passage of food from the farm to the dinner table. This is equally true whether the production is on our own farms or those overseas. To this end the Council is keeping in touch with research on production throughout the Commonwealth and, where possible, in other countries from which our food comes. The establishment of the Overseas Research Council, of which the Council's Secretary is an *ex officio* member, will, it is hoped, help to strengthen the links already existing between the overseas producer and those responsible for handling and processing imported foodstuffs in this country.

FARM BUILDINGS RESEARCH

There is still much misunderstanding of what is involved in research on farm buildings. The need, as it is often stated, is for an assurance that the farm buildings now being put up under the Farm Improvement Scheme are of the best design and that they are likely to remain so for their normal expected life. This is a most reasonable question for the landowner or farmer to ask, but it should be addressed to the architect, or the advisory officer, to answer from his general knowledge of farm building design and his particular knowledge of the holding which the building is to serve. To address the question to the research worker does not make sense ; the whole object of his work is to seek new knowledge which will enable better buildings to be designed in the future. The research worker is only concerned with the present design of any particular type of building, as a point of departure from which he can start out on his search for the knowledge needed to improve it. In most branches of agricultural research this is generally accepted ; the farmer asks the advisory officer which is the best variety of wheat to grow ; he asks the research worker to produce for him a better variety. The difference lies, of course, in the time factor. The farmer is selecting his wheat for one year ; the landowner is putting up buildings which are to last for at least twenty to thirty years.

How then can we best help the landowner with his problem? The first and most obvious step is to make available to him and to the architect, or whoever may be designing his building, all the knowledge at present available in the simplest and most accessible form. This was the initial task which the Council set itself, and which has now been completed. During the year under review an examination was made of all the available printed information on farm building design, amounting to some 7,000 items in all, and of these roughly 1,000 have been abstracted. These abstracts, together with summaries evaluating the different sources of information, are now being published in pamphlet form. The pamphlets do not contain specimen plans and specifications—these are to be found in the publications of the Ministry of Agriculture, Fisheries and Food—but they do aim to provide as much as possible of the information necessary to adapt specimen plans to the needs of a particular farm, or to design a building for a special purpose where this is required.

The second step is to find out as much as possible about existing buildings, how far they meet the needs of different types of holding and in what ways they are unsatisfactory. Progress from this point can follow two lines—research or invention. In research, knowledge is built up by planned experiment designed to answer a definite question or group of questions. An example of this type is the work which the Council is financing at the Institute of Animal Physiology with the object of determining the optimum environmental conditions for the growth of pigs at different ages. Such an investigation can only be carried out by scientifically trained workers with the facilities available in a research institute, or a University. The Council is expanding work of this type wherever the problem can be clearly defined and research workers with the necessary special skills are available. Invention is an entirely different process. The first stage in this is the realisation of the possibility of simplifying some task by, in the case of a building, a change in design or in structure; the next stage is the emergence of an idea as to how this can be accomplished. Scientific training is not called for in these first stages of invention, only an intimate knowledge of the job to be done and a fertile imagination. The development of an invention concerned with farm buildings, from the first idea to the final plan and the testing of its efficiency in practice, does, however, with few exceptions, call for scientific training and special facilities. The Council has therefore been giving careful consideration to the way in which new ideas arising from invention in this country, or from our knowledge of new types of building overseas, could be developed and tested.

It was felt that any plan for the development and testing of farm buildings must have certain essential features. The first is that any new type of structure or layout should be developed and tested under practical farming conditions. There are many examples in all fields of research of ideas which have worked well under the controlled conditions of a research station with its specialised staff, but failed on the ordinary commercial farm. The second is that, although the work must be carried out under practical conditions, the planning and recording must be under the supervision of trained research workers if the results are to be of value for general application. Finally the building should, if possible, be so placed that it will be of permanent value

when the period of trial is completed. (An announcement was made in Parliament on 16th February, 1960, of a scheme of co-ordinated experiments to be administered by the Council, under which grants, up to a maximum of 50 per cent of the approved cost, will be available for the erection in approved cases of experimental buildings or structures on farms or for incorporating experimental features in traditional buildings.)

MONITORING OF RADIOACTIVITY IN THE FOOD CHAIN

The Council has continued to develop its work on the movement of radioactive materials through the food chain and the resulting levels in human diets. During the year the facilities for radiochemical analysis at Wantage were expanded so that all the samples could be analysed there. The Council is greatly indebted to the Atomic Energy Authority for carrying out analytical work at Woolwich until its own laboratory was equipped and staffed for the purpose and for making available temporary accommodation for this laboratory at Wantage until the permanent laboratory at Letcombe Regis is ready. The first report on the results of monitoring, covering the calendar year 1958, was published by H.M.S.O. in July 1959 ("Strontium 90 in Human Diet in the United Kingdom, 1958"). It is proposed to publish reports at approximately six-monthly intervals, each giving the figures for the last full year available, e.g. the next report to be published early in 1960 will cover the period from 1st July, 1958 to 30th June, 1959. By adopting this method of publication seasonal variations are eliminated and the figures in successive reports are comparable. The monitoring in the United Kingdom is now more comprehensive than that in any other country. Workers in the Council's laboratories have also made major contributions to the knowledge of how radioactive materials enter food. Their advice and help is continually being called on by international organisations.

Since the publication of its report (Cmd. 9780) on the hazards to man of nuclear and allied radiations in 1956 the Medical Research Council has kept the subject under constant review and has recently begun to prepare a comprehensive assessment of the significance of all the evidence now available.

FINANCING RESEARCH IN THE UNIVERSITIES

Discussions on this extremely complicated subject have been continued during the year without any definite decision having been reached. What is needed is a scheme acceptable to the Universities that will enable money to be placed at the disposal of departments actively engaged in research work. Whilst the Council has the funds to do this for short periods—usually of three years—it cannot, save in the exceptional circumstances in which the setting up of a Unit is justified, give continuous support. The Council's grants enable a member of a University staff to have the necessary help for long enough to show the value of his work. The problem to be solved is whether funds for the more permanent arrangement which has thus been justified should be provided by the Council as a direct grant or as a part of the University Grants Committee's quinquennial grant to the University.

FEEDING STANDARDS FOR LIVESTOCK

The Council has been asked to undertake an extensive examination of the standards used in the rationing of farm animals and has agreed to do so.

The basis on which our livestock rations are calculated is out of date and is known in many respects to be faulty. There is a voluminous international literature on the subject, but it is difficult, if not impossible, for the food compounder or the farmer to extract from it the information he needs. Many of the results reported have been obtained under circumstances not applicable in this country, either due to major differences in the composition of the feedingstuffs used or to the environment in which the animals are kept. Different workers use different terminology so that it is often difficult to compare one set of figures with another. Finally some of the standards which have found their way into the literature are based on inadequate experimental data. To deal with this problem the Council has set up a committee of experts, which has entrusted to a number of working parties the task of extracting from the literature the best available information and preparing standard recommendations for the rationing of different types of livestock. At the same time the work on the redetermination of feeding standards, which has been in progress for some years, continues with undiminished vigour.

BLOOD GROUP TYPING IN CATTLE

There is a growing demand for a service in the U.K. for typing blood groups in cattle similar to those operating in the U.S.A. and Denmark. The organisation and running of such a service is not the function of a research council. It is a routine activity carried out for commercial purposes. A co-operative organisation formed by the breed societies might appropriately undertake this responsibility. The Council has, however, in its Animal Breeding Research Organisation, been supporting research into the problems involved in the typing of blood groups in cattle and has offered its help to any group establishing a service. This help would take the form of providing in the headquarters building of the Animal Breeding Research Organisation accommodation and training for the workers employed by the Service and advising on any difficult or abnormal specimens which might be submitted.

SYNTHETIC OESTROGENS AND ANTIBIOTICS

The use of these substances as additions to animal feedingstuffs has been under review throughout the year. With both groups of substances two questions have to be considered: the first is the possibility of harm to the human population or to the animals themselves which may arise from their widespread use; the second is the true economic value to the farmer resulting from their addition to feedingstuffs.

The Council has arranged for experiments to be carried out to determine how far the feared dangers from feeding synthetic oestrogens are real. Whilst evidence has been obtained which shows that some of the dangers at first thought to be important are not so, adequate assurance still has to be obtained in respect of other possible hazards. At the same time, in the U.S.A., doubts have been expressed about how far these substances can be used with safety. The Council is in close touch with the American workers and is reporting immediately to the agricultural departments the results of its own findings and those of workers in other countries, particularly the U.S.A. The economic value of feeding synthetic oestrogens turns on the way in which the weight gain accruing is distributed between the different constituents of the carcass and also whether there is any significant change in

the quality of the meat. Whilst the evidence so far available points to changes in carcase composition, it does not show that any adverse effect on carcase quality results from the proper use of these substances.

The feeding of antibiotics has been shown to give gains in growth rate in pigs and poultry although this does not hold under all circumstances. It can, however, be generally accepted that there is an economic return in growth rate on the feeding of antibiotics to non-ruminants. The risks accompanying the continuous administration of antibiotics must, however, be closely considered. It is well known that in the presence of antibiotics resistant strains of pathogenic organisms can develop, which may be dangerous both to man and animals. Whilst, therefore, it may be relatively safe to feed antibiotics to fattening or young growing animals for short periods, the continuous feeding of these substances could result in the emergence of a strain of pathogens which no longer responded to antibiotic treatment. It is almost impossible to obtain experimental evidence of how general such an effect is likely to be, or whether the resistant strains would arise when antibiotics were used continuously at low concentrations. There is definite medical evidence that this does happen when antibiotics are used continuously in higher concentrations for therapeutic purposes. It has been strongly argued that the risk in feeding antibiotics is small and the economic gain considerable and hence that in the interests of efficiency the risk should be taken. Unfortunately, if antibiotics are fed more and more widely to farm animals and resistant strains of pathogens appear and persist, the damage will have been done and we may be faced with conditions in both man and animals which no longer respond to these invaluable therapeutic agents. The problem, however, is regarded as of great urgency and the evidence, as it is accumulated and assessed, is made available to the agricultural departments. The Council cannot at present advise the wider use of these substances in animal feeding-stuffs.

ADMINISTRATION AND FINANCE

1958-59

ROYAL VISIT

The Grassland Research Institute was honoured by a visit from H.R.H. Prince Philip, Duke of Edinburgh, on 2nd May, 1958.

OBITUARY

The Council records with regret the death on the 20th December, 1958, of Professor E. J. Maskell, M.A., Ph.D., F.R.S., who was a member of the Council from 1952 to 1957.

STAFF

At the close of the year under report there were 4,115 members of staff employed at the agricultural research institutes. Of this number 817 were in the Scientific Officer class, 593 in the Experimental Officer Class and 802 in the Assistant (Scientific) Class. The remainder were mainly in the

Executive, Clerical and Industrial classes. The number of staff employed in the Council's Secretariat was 75.

CHANGES IN DIRECTORSHIPS

Sir William G. Ogg retired from the Directorship of Rothamsted Experimental Station and Mr. F. C. Bawden (formerly a Deputy Director and Head of the Plant Pathology Division) was appointed Director from 1st October, 1958.

Dr. I. de Burgh Daly retired from the Directorship of the A.R.C. Institute of Animal Physiology and was succeeded by Dr. J. H. Gaddum, who was appointed on 1st October, 1958.

Professor H. D. Kay retired from the Directorship of the National Institute for Research in Dairying and the Deputy Director, Dr. A. T. R. Mattick, was appointed Acting Director with effect from 1st October, 1958.*

Professor E. T. Jones retired from the Directorship of the Welsh Plant Breeding Station and was succeeded by Professor P. T. Thomas on 1st October, 1958.

Professor F. G. Gregory, Director of the Research Institute of Plant Physiology retired on 31st December, 1958. The Institute, as such, was dissolved and in its place the Council has set up two Units formed from members of the staff of the Institute. One is the Unit of Plant Physiology at the Imperial College of Science and Technology under the direction of Professor Helen K. Porter and the other the Unit of Plant Morphogenesis and Nutrition located at Rothamsted Experimental Station, under the direction of Dr. F. J. Richards. Certain members of the staff of the Institute who had been located at East Malling Research Station have been absorbed into the staff of that Station.

Dr. R. Brown resigned the Directorship of the A.R.C. Unit of Plant Cell Physiology on his appointment to the Chair of Botany in the University of Edinburgh and the Unit was disbanded, a number of its staff being transferred to the John Innes Horticultural Institution.

OTHER APPOINTMENTS

Dr. Ian A. Galloway, the Director of the Foot-and-Mouth Disease Research Institute, was promoted to the grade of Chief Scientific Officer on 1st April, 1958.

Dr. J. H. Sang was appointed Deputy Director of the A.R.C. Poultry Research Centre from 25th July, 1958.

HONOURS AND AWARDS

Her Majesty the Queen conferred the following honours:—

Knight of the Garter	...	His Grace the Duke of Northumberland, Chairman of the Council.
Baron		Lord Netherthorpe, Member of Council.
C.B.E.		Dr. I. de Burgh Daly, lately Director of the A.R.C. Institute of Animal Physiology.

* Dr. Mattick retired on 30th September, 1959 on reaching the age limit. Professor R. G. Baskett, O.B.E., was appointed to the Directorship from 1st August, 1959.

C.B.E.	...	...	...	Professor C. H. Waddington, Honorary Director, A.R.C. Unit of Animal Genetics.
C.B.E.	...	...	...	Professor S. J. Watson, Member of Council.
O.B.E.	...	...	...	Mr. H. V. Garner, Rothamsted Experimental Station.
M.B.E.	...	...	...	Mr. H. H. Tydeman, East Malling Research Station.

Professor G. E. Blackman, Honorary Director of the Council's Unit of Experimental Agronomy, was elected a Fellow of the Royal Society.

LECTURES

Sir William Slater addressed a meeting of the Fertiliser Society in London on the 27th November, 1958, taking as his subject "Science in the Service of Agriculture" and, on the 12th January, 1959, inaugurated the Share-Jones lectures when he delivered the first of two addresses at the University College of North Wales, Bangor, on "Animal Husbandry: Present and Future".

VISITING GROUPS

The following institutes received Visiting Groups during the year:—

Agricultural Research Council Field Station, Compton, Berkshire.

Agricultural and Horticultural Research Station, Long Ashton, Bristol.

East Malling Research Station, Maidstone, Kent.

Rowett Research Institute, Aberdeen.

SCIENTIFIC COMMITTEES

The Council and its Standing Committees have continued to be assisted by Committees and Conferences of scientists and agriculturists particularly interested in various fields of work.

The Veterinary Therapeutic Testing Board, set up in 1957 to administer a scheme for the impartial testing of substances used or ordered for use in veterinary medicine, has continued its work but, as in the previous year, there have been few applications for it to consider and in no case was a full scale trial initiated.

The Council set up a Committee known as the Committee on Farming Activities to enquire into the general efficiency of farm management at the research institutes and to institute a system of accounts to serve as a guide to farming efficiency.

During the year most of the several committees which had previously kept under review specific diseases of cattle and sheep were dissolved, as it was felt that their functions could be exercised more effectively by a general committee which would convene *ad hoc* conferences as required on any special aspect of animal diseases. Accordingly a Technical Committee on Sheep and Cattle Diseases was established, and the following committees dissolved:—

Technical Committee on Brucellosis.

Technical Committee on Calf Diseases.

Technical Committee on Johne's Disease.

Technical Committee on Mastitis.

Conference of Workers on Mastitis.

In addition the Technical Committees on Mineral Metabolism and on Dairy Machinery were dissolved. The Technical Committee on Scrapie Research has been retained in being in view of the special problems presented by this disease and the need for continued close co-ordination of the work.

Groups set up by the Technical Committee on Poultry Research to review research on poultry respiratory diseases and research requirements relating to poultry housing completed their tasks by reporting to the Technical Committee and were disbanded.

A number of *ad hoc* conferences was held to consider research in progress, or required, on particular subjects including a meeting of workers on insecticides, fungicides and herbicides, and on the control of bracken by mechanical and chemical means. A conference on current trends in research and practical control of apple scab was arranged. A meeting was held to consider the nutrient and other effects of farmyard manure. Suitably constituted working parties are examining in more detail the issues raised. Other conferences were held to discuss ketosis (acetonaemia) in dairy cattle, enteritis in pigs, and salmonellosis in poultry.

OVERSEAS LIAISON

A great number of visitors from abroad was received at various agricultural research centres during the year. Many of them came under scholarships and fellowships awarded by the British Council, the World Health Organisation or the Food and Agricultural Organisation, while others were nominated by their Governments for further training under such schemes as the Colombo Plan, the Baghdad Pact and the Yugoslav Technical Aid Scheme.

Following a request by the Soviet Embassy in London, arrangements were made through the Soviet Relations Committee of the British Council for two agricultural research workers from Russia to spend a year at Rothamsted Experimental Station; two scientists from Rothamsted visited Russia to work at Moscow University for a similar period. A programme of visits to research institutes was also arranged by the Council for a senior scientific worker from the Research Institute of Plant Breeding and Animal Husbandry, Western Ukraine. Under the auspices of the British Council plans for further exchange visits between Russian and British agricultural research workers were made during the year.

Over 200 grants were made by the Council to enable members of the agricultural research service to visit research centres abroad or to take part in a number of scientific conferences, including the 10th International Genetics Conference at Montreal, the World Poultry Congress in Mexico, and the International Biometrical Congress at Ottawa.

Other scientists from the service went abroad during the year under the auspices of international organisations, Commonwealth and foreign Governments and foundations for the purpose of investigating and advising upon overseas problems or in order to widen their own experience.

The Secretary of the Council attended the meeting of the Standing Committee of the British Commonwealth Scientific Conference at Vancouver in August 1958. Dr. Cheesman, one of the Scientific Assistants to the Secretary, represented the United Kingdom at a meeting of the Sub-Commission on

Agricultural Research of the Food and Agriculture Organisation, in Copenhagen.

BUILDINGS AND PROPERTY

Several major schemes were completed during the year. These included new laboratories for the Bacteriology and Chemistry departments of the National Institute for Research in Dairying; an additional laboratory building at the Virus Research Unit, Cambridge; buildings for mushroom research at the Glasshouse Crops Research Institute; animal accommodation at the Moredun Institute and at the Rowett Research Institute; a laboratory for climatological studies, mainly in sheep, for the Animal Breeding Research Organisation; a new sub-station of the Poultry Research Centre, Edinburgh. Glasshouses were completed at the Plant Breeding Institute, Cambridge, for research on cereal disease and on potatoes and brassicae and at Rothamsted Experimental Station for the Entomology and Insecticides Departments.

The major works in progress at the end of the year 1958-59 were:—

Glasshouse Crops Research Institute: Administration Block.

Hannah Dairy Research Institute: extended laboratory and animal accommodation for the Nutritional Physiology Department.

Houghton Poultry Research Station: new laboratory wing and adaptation of main building for administration.

Long Ashton Research Station: new laboratories, canteen and common room block.

National Vegetable Research Station: permanent laboratory block.

National Institute of Agricultural Engineering: new Hydraulics laboratory.

Field Station, Compton: a major extension to the sewage disposal works.

Macaulay Institute for Soil Research: new laboratory accommodation.

The Council gave its support to proposals for new premises for the Scottish Station of the National Institute of Agricultural Engineering; for microbiological laboratories at the Moredun Institute; and for laboratory extensions at the Scottish Horticultural Research Institute. It also approved in principle the provision of additional laboratory accommodation at the Unit of Reproductive Physiology and Biochemistry, Cambridge.

During the year, the Council purchased the 38-acre estate of Letcombe Manor, Letcombe Regis, near Wantage, Berks to provide headquarters and laboratory accommodation for the Radiobiological Laboratory.

LAND AGENCY SERVICE

Good use has continued to be made by research institutes of the professional services provided by the Council's Land Agents, Messrs. W. H. Cooke and Arkwright, whose advice is available to all the State-aided institutes in England and Wales as well as to all the Council's own establishments.

TESTING OF VITAMIN D PREPARATIONS

The scheme under which samples of cod liver oil and synthetic vitamin D preparations intended for poultry are tested by the National Institute for Research in Dairying on behalf of the Ministry of Agriculture, Fisheries and Food has continued. Samples purchased by officers of the Ministry from commercial sources are referred informally to the Institute for test and report, and the facts concerning any unsatisfactory samples are brought to the notice of the manufacturer.

AGRICULTURAL RESEARCH FUND

The greater part of the Council's expenditure is met from the Agricultural Research Fund which is financed by a Parliamentary grant-in-aid. In the financial year ended 31st March, 1959, gross current expenditure was £3,916,981; capital expenditure on buildings and special apparatus amounted to £462,475. A grant-in-aid of £4,196,000 was voted by Parliament, of which £4,110,000 was drawn. The grant-in-aid was augmented by receipts totalling £231,847 derived from sales of livestock, produce, etc., at research institutes and units, from rents and hostel charges, and from the sale of publications and reports, as well as by contributions totalling £39,577 from Government Departments and other sources. These contributions included £15,885 from the Hops Marketing Board and the Institute of Brewing towards the cost of research on hops at Wye College; £10,000 from the Animal Health Trust towards the maintenance of the Houghton Poultry Research Station; £6,389 from the Colonial Office towards the cost of the Council's Unit of Experimental Agronomy; £5,288 from the Colonial Office towards the cost of work on tropical soils and for research on insecticides at Rothamsted Experimental Station; and £1,565 from the Forestry Commission for research at Rothamsted on the nutrition of forest trees.

The allocation under main heads of the total expenditure from the Agricultural Research Fund was as follows:—

	£	Percentage of total
Administration	126,215	2·9
Research institutes and units of the Council:		
Current expenditure	1,152,362	26·3
Capital expenditure	103,013	2·4
Special research grants	138,430	3·2
Studentships, training awards and fellowships (including travelling fellowships for visits overseas)	48,111	1·1
Grants to independent research institutes (England and Wales):		
for current expenditure	2,451,863	55·9
for capital expenditure	359,462	8·2
	£4,379,456	100·0

GRANTS MADE FROM THE VOTE OF THE DEPARTMENT OF AGRICULTURE FOR SCOTLAND

Grants to the independent agricultural research institutes in Scotland are made from the Vote of the Department of Agriculture for Scotland, on the advice of the Council. For the financial year which ended on 31st March, 1959, the total of such grants was £771,715 for current expenditure and £76,746 for capital expenditure.

BENEFACTIONS

By the terms of its Charter, the Council is empowered to accept and administer private funds or properties which may be given or bequeathed to it in trust, either for the general purpose of its work or for special objects within its field.

(a) *The Underwood Fund*

This fund, of which the income during 1958-59 was £3,660, has continued to be used by the Council to provide Fellowships or grants for distinguished overseas scientists who wish to visit this country and who are likely, directly or indirectly, to assist the Council's work. The Council is willing to consider applications for Fellowships by, or on behalf of, such scientists, at any time of the year.

Two awards were made in 1958-59. The first enabled Dr. Lewis E. Lloyd, Associate Professor of the Department of Nutrition, Macdonald College of McGill University, Canada, to spend a year at the Rowett Research Institute. The second was a grant of £250 towards the expenses of Professor R. Dulbecco of the California Institute of Technology, who spent a period in this country.

(b) *The Wain Fund*

The objects of this fund, which was established in 1958, are to facilitate the interchange of scientists between universities in the United Kingdom and overseas; to provide equipment in the universities in the United Kingdom for agricultural research; and to further other schemes of benefit to agricultural research for which the ordinary funds of the Council are not available.

No payments were made from the Fund during the financial year 1958-59. The balance carried forward at 31st March, 1959, was £2,576.

FINANCIAL ASSISTANCE FROM OUTSIDE BODIES

The Council gratefully acknowledges the assistance received during the year from the following bodies:—

(1) *W. K. Kellogg Foundation*

The Foundation provided four Fellowships to enable workers in the agricultural research service to spend study-periods of up to six months in the United States and, once more, made available £1,000 in dollars for the purchase of scientific equipment in that country.

(2) *Hatley Foundation*

Grants amounting to \$3,000 were made from funds placed at the disposal of the Council by the Foundation, making it possible to send three scientists to visit research institutes in Canada and the United States of America.

(3) *Rockefeller Foundation*

The Foundation made a grant of \$20,200 to the Rowett Research Institute for the purchase of expensive equipment to be used in research into animal nutrition and physiology ; to Rothamsted Experimental Station a grant of \$75,000 to aid studies for a further five years on extraction of proteins from waste vegetable matter and to the National Institute for Research in Dairying a grant of \$3,600 for the purchase of equipment for the Physiology Department.

The Council also wishes to express its thanks to the Rockefeller Foundation, the Royal Society, Nuffield Foundation, the Wellcome Trust, the National Research Council of Canada, the New Zealand Government and the National Science Foundation of America for the awards of travelling fellowships made during the year to members of the staffs of the research institutes.

NORTHUMBERLAND,

Chairman of the Agricultural Research Council.

W. K. SLATER,

Secretary of the Council

Cunard Building,

15, Regent Street,

London, S.W.1.

19th January, 1960.

SOME ASPECTS OF AGRICULTURAL RESEARCH

FOOT-AND-MOUTH DISEASE

The purpose of this short review is to give an appreciation of the advances that have been made in research into foot-and-mouth disease and to indicate the increasing contribution that the Pirbright Institute has been making since greater facilities were made available. Before doing so, however, it will be useful to sketch in a certain amount of background.

INTRODUCTION

A Departmental Committee was appointed in 1952, under the chairmanship of Sir Ernest Gowers, "to review the policy and arrangements for dealing with foot-and-mouth disease in Great Britain and to advise whether any changes should be made in the light of present scientific knowledge and the technical and administrative experience gained in recent years in this and other countries". The Committee, which reported in 1954, made a number of valuable recommendations for alteration and improvement in the arrangements for dealing with outbreaks of the disease but gave full support to the stamping-out policy, involving slaughter of infected and contact animals and accompanying measures for the prevention of the spread of infection.

These decisions have been fully justified by events since 1954. The disease position throughout the greater part of Europe is more satisfactory than it has been for the last twenty-five years but the method of control and eradication followed by Great Britain is not generally applicable. In a few European countries and in parts of Asia, Africa and South America the disease is endemic, and a combination of a large stock population kept under difficult conditions of husbandry, with an often inadequate veterinary organisation, maintains infection which may then be conveyed to other areas directly by stock movements and by trade in animal products or indirectly by a variety of means.

The European Commission for the Control of Foot-and-Mouth Disease published an overall plan for Europe which is realistic and is reproduced since it covers the essential needs for any set of circumstances.

"In those countries where a heavy weight of infection is present or where there is a continued threat of infection, the policy should be systematic vaccination. The system may vary in accordance with the circumstances in the particular country. It may be possible, for example, to adopt annual vaccination of all cattle stock in the country, or vaccination may be done around foci of infection or in threatened areas. When the number of outbreaks has been sufficiently reduced, vaccination may be supplemented by slaughter of animals on infected premises. Later, there may be a reduction in routine vaccination and the stamping-out policy may be adopted as the main method of control. This stage may not be reached in a particular country until its neighbours and countries from which imports, particularly

of livestock, are made have reached a similar position. Only after this stage will it be possible to rely entirely on a stamping-out policy.

“It is obvious that sufficient supplies of trustworthy vaccines must be available and that there is a staff capable of organising and carrying out the vaccination. It must be emphasised that, whatever the policy, it is essential to control the movement of stock, to dispose of infected material and to carry out effective disinfection.

“The Committee was impressed with the success of the vaccination policy in those countries where it has been systematically applied. Not only has the number of outbreaks been reduced, but the weight of infection has been minimised, because, as a general rule, only young cattle and pigs have succumbed to infection.

“In order to have a stamping-out policy, the following points must receive careful application:

1. Early notification of a suspicion of the presence of the disease must be available.
2. A very meticulous system of dealing with such reports must be in force and must be readily put into effect—the system must include rapid diagnosis—immediate control of movement of stock over an area—immediate quarantine of the suspected or infected farm—tracing of all contact animals and slaughter of direct contacts on other farms, e.g. animals recently moved off the infected place and animals handled by the owner of the infected place or his veterinary surgeon after contact with infection.
3. Rapid means of slaughter and disposal of carcasses on the infected place.
4. An organisation capable of dealing with all the detailed tracing of stock which is necessary.
5. A system of recording movements of stock must be permanently in force and enforced to allow of easy tracing of animals.
6. Visits to examine stock in the vicinity of outbreaks must be made to discover secondary outbreaks as early as possible and also to discover whether the first reported case is in fact the primary one.
7. There must be considerable elasticity in financial arrangements to allow of vigorous pursuit of the policy.
8. The farming community must be willing to co-operate in every aspect of the work.”

“In most European countries a stamping-out policy, not supplemented by vaccination, is impracticable but the Committee regards a stamping-out policy as the ultimate objective.”

The systematic use of vaccine has resulted in virtual control of the disease in many European countries. The system of vaccination has varied from annual vaccination of all cattle, supported by arrangements for vaccination of all young stock before sale, to vaccination around infected farms and vaccination of all cattle in frontier districts neighbouring other infected countries. In several instances vaccination has been supplemented by slaughter of all animals on farms or by slaughter of infected animals

and susceptible contacts (unvaccinated young cattle as well as pigs and sheep). As a result of improved control by these means each outbreak recorded from countries where these arrangements are followed no longer represents a source of heavy or continuing infection and the spread of virus within the herd is minimal.

It is believed that infection was at one time conveyed to Great Britain from Holland, Belgium and Denmark by birds when heavy infection was present at the time of bird migrations. On the last occasion (1951) the numbers of outbreaks in these three countries were 20,751; 50,359 and 23,492 for the year. For 1959, up to the end of October, they were 6, 1 and 60 and for the five years 1954–1958 they have averaged 37, 509 and 30. Great Britain has clearly benefited from the better control of disease by vaccination in these countries and can benefit still further by the extension of systematic vaccination in other parts of the world.

At present vaccines are available against the three well known types of virus which are found in Europe and South America: A, O and C. Other virus types are, however, encountered in Africa and Asia. Three immunologically separate types occurring in Africa have been recognised at Pirbright; S.A.T.I, S.A.T.II and S.A.T.III, and in Asia a separate type, Asia 1, is met. If vaccination systems practised in Europe and South America are to succeed, exotic types of virus must be excluded, since the vaccines in use provide no protection against them. It is therefore highly important to develop vaccines against these viruses. That this is a real problem may be illustrated by the fact that disease has been conveyed from time to time from Turkey to Balkan countries. Turkey has close contacts with Syria where Asia 1 virus has been recognised. It is undesirable to work with these exotic types in laboratories on the mainland of Europe owing to the possibility that virus will escape, and international organisations have consistently recommended against it. One of the outstanding contributions which may be made from Pirbright is, however, the investigation of these exotic viruses, for not only are the safety precautions against the escape of virus extremely effective there, but even so, if there should happen to be an escape of exotic virus it would be stamped out and would not break the system of control used in this country.* It is encouraging to know that progress has already been made.

EPIDEMIOLOGY

Survey Work

Like the viruses of poliomyelitis, influenza, equine encephalomyelitis, vesicular stomatitis and vesicular exanthema, the virus of foot-and-mouth disease possesses many strains of different immunological types. Infection with any strain of virus leaves the recovered animal protected for a considerable time against reinfection with that strain or a strain of the same type of virus, but the animal can be infected immediately with another strain of virus of different type. It is essential therefore in any outbreak of disease to know the type of virus concerned and for this reason the immunological classification of 3,000 specimens of virus recovered from outbreaks which occurred in forty-five countries throughout the world has been undertaken at Pirbright.

* Since this was written, there has been an escape of an exotic virus. The infection was quickly stamped out and there was no secondary outbreak.

Considerable differences are sometimes found between strains of virus isolated from different outbreaks of the disease; differences in the facility with which the virus can infect the several susceptible species of farm animals, cattle, pigs, sheep or goats; in the readiness with which it spreads from animal to animal; in the severity of the disease it produces; and in the immunity that follows infection or vaccination with it.

Some strains of virus from outbreaks in swine have been shown to be more infective for pigs than for cattle, while some strains from cattle have special affinity for cattle. A detailed study of the characters of the strains of virus recovered from widespread outbreaks in Mexico was of particular value not only in assisting the joint Mexican-American Commission in its control campaign which later included vaccination, but in confirming the occurrence of strains with a particularly low invasiveness which gave rise to a greater incidence of subclinical infection.

The O, A and C types of the virus, which have been recognised for many years in outbreaks in Europe and South America, are the only types encountered in Great Britain. In the course of the epidemiological surveys carried out since 1947 at Pirbright the occurrence of these types has been confirmed in countries in the Middle East; in Asia through to the Far East, Indonesia, Hong Kong, Thailand and the Philippines; in Africa in the North, West, East, Centre and as far South as Nyasaland (type O), Angola and South West Africa (type A); in America, in Venezuela, Colombia, Mexico and once in Canada (the only outbreak ever to occur there).

The Institute established the existence of the three additional types, designated S.A.T.I, S.A.T.II and S.A.T.III, from outbreaks in Africa, and more recently, the existence of the seventh type, Asia 1, was confirmed from a country in Asia. The African types, which were originally found in the Southern African Territories (S.A.T.) have since been detected as far North as the Sudan and Egypt; the Asia 1 strain has been encountered in many countries in Asia and as far west as Afghanistan, Iran, Israel and Syria. These surveys have to be continued to uncover outbreaks due to exotic types—African and Asian strains in Europe, South America and West Africa and European strains (A, O. and C.) in South Africa, the Rhodesias, Mozambique and Bechuanaland.

The surveys made by the Institute have already detected as many as four types of virus in some countries and three in many. In Pakistan and India O.A.C. and Asia 1 have been demonstrated; in Kenya O.A.C. and S.A.T.II; in Afghanistan O.A.C. and Asia 1; and in Southern Rhodesia and South Africa S.A.T.I, S.A.T.II and S.A.T.III.

Prompt reporting is of paramount importance in any system of control, whether it be a slaughter policy or a policy of vaccination; and for quick action, rapid confirmation of diagnosis and type determination may be just as important. There is usually no difficulty in diagnosing a case of foot-and-mouth disease by clinical means in Great Britain, but it sometimes happens that only mild cases occur, or that only one animal is affected in which only a few poorly developed vesicles are present. In these cases it is necessary to resort to laboratory tests for diagnosis; material from all primary outbreaks is, however, sent for typing, as a routine in this country,

and this also serves to confirm the field diagnosis. A positive result on samples of material from outbreaks in Great Britain is obtained quickly in about 80 per cent of cases by the use of the relatively simple complement fixation test. Negative results to this test do not necessarily exclude a diagnosis of foot-and-mouth disease; with material from abroad the percentage of successes may be as low as 20, because of the difficulty in getting specimens from animals at a sufficiently early stage of the disease or because specimens come from partially resistant animals.

When very little virus is present in a sample, the amount may be increased before complement fixation tests are again carried out by passing it through animals. At one time it was necessary to do this in cattle or swine, but baby mice can now be used as it was shown in 1951 that they are susceptible to infection. The average percentage of positive results in material from overseas has been increased to 60 by this device. A further improvement followed the demonstration in 1955 at Pirbright and at the Plum Island Animal Disease Laboratory (United States Department of Agriculture) that foot-and-mouth virus could be grown in cultures of kidney tissue. The use of kidney tissue culture has brought the positive results up to 80 per cent.

The gel diffusion precipitin test, which is mentioned later, may also be used in connection with the Survey.

In addition to studies on the distribution of virus types information on the factors which influence the dissemination of the disease is also gained from the epidemiological surveys. This has a considerable bearing on the developments of methods of control and in the assessment of the risks associated with movement of domestic and wild animals and with trade in a great variety of animal products.

World Reference Laboratory

It is realised that information about the distribution of types of virus and accurate identification of the strains involved in outbreaks is essential for the preparation of appropriate vaccines. In recognition of the work it had already done in this field, the Pirbright Institute was designated as a World Reference Centre for foot-and-mouth disease, following negotiation between the Food and Agriculture Organisation of the United Nations and H.M. Government. This development also has the support of the European Commission for the control of foot-and-mouth disease.

The functions of the Reference Laboratory include the making of surveys, the classification of types and sub-types of virus and the establishment of a collection of these and of antisera to them. Antisera to the seven recognised types are already available and are supplied to some countries. Antisera are also held for two diseases which clinically resemble foot-and-mouth disease—vesicular stomatitis and vesicular exanthema. (It has been announced that vesicular stomatitis has been eliminated from U.S.A. and since it has not been recorded elsewhere, this may mean that the disease has been completely eradicated.) The Institute does not undertake routine examination of virus material from European countries or the Americas since facilities are already available elsewhere, but assistance is given on request.

Vaccines and Vaccination

All those who are engaged on research on foot-and-mouth disease or who are responsible for effective control of the disease by vaccination, supplemented or not by slaughter, agree that the development of improved cheaper and more readily produced vaccines must receive the closest attention. For the control of virus diseases two types of vaccine can be considered; one in which the virus has been inactivated, and the other a live vaccine prepared from a modified or attenuated strain of virus. Which-ever type of vaccine is developed in respect of foot-and-mouth disease the problem is complicated by the need for effective vaccines for all seven types of the virus; indeed sub-types within each type may be sufficiently different from each other to require specific vaccines.

(a) *Inactivated vaccines.* In the 1920's it had already been demonstrated independently by British and German scientists that the virus of foot-and-mouth disease could be grown in cultures of guinea-pig tissue, and this virus and that of vaccinia were the first to be propagated in tissue and cultures. Within the last ten years, as a result of long and patient research, a method, with which the name of Frenkel of Holland is associated, has been developed for growing virus on a large scale using the epithelium of the tongue. This method of growing virus has many advantages in the preparation of vaccines over the former method of infecting cattle and collecting the virus from them when they develop the disease. The first series of tests under strictly controlled conditions, made at the Pirbright Institute, to compare the protective value of culture virus vaccines and cattle virus vaccines, showed that the vaccines were equally effective. Several large batches of vaccine have been prepared from different types of the virus and have been tested with satisfactory results.

In preparing the vaccine, virus is incubated with formalin to a point at which it is no longer infective but still retains its immunising properties. Inactivating agents other than formalin are being tried and experiments using small laboratory animals and agar diffusion precipitin tests suggest that improvements in vaccinating properties may be made along these lines.

The preparation of vaccines from virus grown in kidney tissue culture is being investigated in several laboratories in Europe and South America, including Pirbright, as in most countries kidneys are more easily procured than the large amount of cattle tongue epithelium required for production on a practical scale.

(b) *Live Vaccines.* Live vaccines are prepared by modifying or attenuating virus by growing it in chick embryos, in tissue cultures, or in animals which are not normally affected by the disease. This is carried to a point when the virus no longer produces disease in the original host though its immunising value is retained. Such vaccines are currently used for small-pox, rinderpest, rabies, horse sickness and blue tongue, and attention recently has been given to the possibility of developing them for foot-and-mouth disease and poliomyelitis in man. They can be produced more easily than inactivated vaccines; they are effective in smaller doses and they appear to give a longer immunity. For several years work has been going on at Pirbright on the modification of cattle strains of the virus of foot-and-mouth

disease to reduce their infectivity for cattle to a point at which they could be used as vaccines.

The work on attenuation of the virus of foot-and-mouth disease flows from the demonstration that unweaned mice can be infected with it and that the virus can be propagated in day-old chicks and in chick embryos inoculated by the intravenous route. Attenuation of the various strains of the virus has been achieved by serial passage in baby mice inoculated intraperitoneally, in mice over four weeks old inoculated intramuscularly and in 14-day chick embryos inoculated intravenously. Adaptation of the virus to chick embryos and to adult mice is more easily achieved when it has first been grown in unweaned mice. Whatever method has been used for modifying the virus, high infectivity for unweaned mice has been maintained while progressive reduction in infectivity for cattle has been achieved. Several representative modified strains for each of the seven immunological types of the virus have been developed and about a thousand cattle have been used to investigate their immunising properties.

The degree of attenuation for cattle which has been achieved has been assessed by estimating the dose required to produce typical vesicles when inoculated into several places on the tongues of cattle about eighteen months old. When a strain fails to produce vesicles in at least six of eight inoculated cattle, it is considered ready for test as a vaccine. Tests for immunity have usually been made about three weeks after vaccination by challenging the vaccinated animals and control animals with cattle virus. The levels of antibody in the serum of vaccinated animals have been observed and a good correlation found between the results of the challenge tests and the serum tests.

The encouraging results of experiments made up to April, 1959, were reported at the International Veterinary Congress held in Madrid. The work with these attenuated strains is continuing as there is still much to be done; it is necessary to investigate, for example, storage under different conditions, bulk production, behaviour in tissue culture, transport without loss of potency, and the duration of immunity conferred by the strains. Efforts must be made to improve their immunising properties and to investigate polyvalent vaccination.

All the experiments with attenuated virus have been made on susceptible cattle which have had no previous exposure to the virus of foot-and-mouth disease. In practice, however, the vaccines would usually be required in areas where the disease is endemic and where there are likely to be cattle which have had past experience of infection with one or other of the virus types, or which have been vaccinated at some time with inactivated virus vaccines or which have a passively transmitted immunity. It is essential, therefore, to know the effects of the inoculation of these live attenuated strains into cattle in such areas. Furthermore zebu or humped cattle may be encountered in some places and buffalo in others. Zebu cattle do not react in the same way as the more common breeds, probably as a result of a certain measure of natural breed resistance and it is not easy to interpret the results obtained in these animals in view of the poor reactions of unvaccinated control animals challenged with cattle virus. A similar situation may be presented by the buffalo in Thailand. Experiments are,

therefore, being conducted in Africa and in Thailand to study the behaviour of vaccine strains in the field; these are run concurrently with tests at Pirbright of the same strains at the same passage level. The results obtained so far are encouraging, but it is not yet possible to assess the position fully.

Work on modified strains for vaccination is being done in Brazil, France and Russia (lapinised vaccine) and in Israel (day-old chick or chick embryo vaccine).

LABORATORY INVESTIGATIONS

Most of the measures for the control of foot-and-mouth disease that have been developed in the field have been founded on work which has been done in research institutes. This applies to the disinfectants that are used; the precautions to be taken to prevent the spread of infection, particularly when animals and animal products move from one country to another; and the various vaccines which have been developed. The paragraphs which follow deal mainly with fundamental studies of the virus carried out in the laboratory. Their application to the control of the disease may not as yet always be apparent but it is of real importance that such studies should continue, for it is only by correlating the findings from a great variety of enquiries that full knowledge of the disease can be built up.

Biochemistry

It is well established that the extraction with phenol of animal tissues infected with animal viruses (e.g. poliomyelitis, Eastern equine encephalomyelitis, murine encephalomyocarditis) produces preparations that do not contain virus but nevertheless induce animals to show clinical symptoms indistinguishable from those produced by the virus. At Pirbright (1958) and at Tubingen it has recently been shown that similar preparations can be made from animal tissue and cultures of pig kidney tissue infected with the virus of foot-and-mouth disease. This finding is of considerable fundamental importance, not only in connection with the study of the virus of foot-and-mouth disease, but generally in the study of viruses, and is being followed very intensively at the Institute.

Tissue Culture

The usefulness of tissue culture for the production of virus during the preparation of inactivated vaccines has already been mentioned. The technique has other uses. If a series of cultures of kidney tissue are prepared just one cell thick and they are then inoculated with increasingly dilute suspensions of virus, there will be a group of cultures within a certain range of dilutions of the virus in which, due to the destructive action of the virus on the kidney cells, clear areas or plaques develop on the cultures. The number of plaques is equal to the number of virus units which are put on the culture. This method of counting viruses was first developed by Delbecco in California for studies on poliomyelitis and other viruses and has been used at Pirbright with the virus of foot-and-mouth disease. It has proved of great value in a number of investigations where it has been necessary to grow and detect virus, e.g. in the examination of field samples in epidemiological surveys, in the estimation of the strength or content of virus, in tests on the serum of vaccinated animals in relation to the development

and duration of immunity, in the study of the growth and properties of attenuated strains, in genetic studies on virus populations and in the isolation of genetically marked substrains. Tissue culture techniques may also be used for investigating the latent period of virus growth, especially at the early stages of infection when the virus is penetrating the host cell.

The use of kidney tissue cultures at Pirbright has grown so much that an independent culture unit has had to be set up to supply the cultures.

For certain types of work, however, methods based on tissue culture are less sensitive than the inoculation of virus into the most sensitive sites of naturally susceptible animals. This, the most delicate test, is used for experiments such as the testing of inactivated virus for innocuity and seeing whether the treatment with acid of skimmed milk contaminated with virus renders it safe for feeding to animals.

Genetics

Strains of virus are being developed for genetic study and mutants have already been isolated. The characters under investigation so far are temperature and resistance to acid.

Since unweaned and adult mice are used extensively in research on foot-and-mouth disease, the relative sensitivity of different strains of mice to the virus of foot-and-mouth disease inoculated intraperitoneally or intramuscularly, has been studied, and from the results procedures have been worked out for making the most economical use of mice in experiments involving titration of virus or serum-neutralisation tests.

The Structure of the Virus

Earlier published work from Pirbright showed that it is possible to separate two fractions from suspensions of the virus by differential ultracentrifugation. One fraction contains a component which has a sedimentation content corresponding to a size of about $25m\mu$ and the other of about $7m\mu$. The former is infective and fixes complement, the latter also fixes complement but is non-infective. More recent work has shown that the fraction with the higher sedimentation constant contains particles with a diameter of $25m\mu$ which appear roughly spherical in clusters or hexagonal arrays under the electron microscope. There is evidence that these particles are indeed the infective virus component.

Two precipitation lines are produced if the virus is allowed to diffuse towards homotypic immune serum in agar gel. One line is due to the $25m\mu$ component and the other to the $7m\mu$ component. It has been demonstrated that there are two antibodies and that the $25m\mu$ component combines with heterotypic serum. This has some value in providing a screening test for infectivity of virus and has some practical application in following the effects on the virus of procedures used in the preparation of vaccines, such as freeze-drying, heat or the action of chemical agents, e.g. formalin.

The viruses of herpes, louping ill, myxomatosis, lymphocytic choriomeningitis and Rous sarcoma are all inactivated by anionic detergents and the last two are inactivated by cationic detergents as well. It is also known that naturally-occurring detergents, such as sodium desoxycholate, inactivate the arthropod viruses but the viruses of foot-and-mouth disease, poliomyelitis, equine encephalomyelitis, Cocksackie disease and mouse

encephalomyocarditis are not susceptible to its action. It has recently been shown at Pirbright that the virus of foot-and-mouth disease is highly resistant to the anionic detergent sodium dodecyl sulphate (S.D.S.) and to a cationic and a non-ionic detergent, while in contrast the virus of vesicular stomatitis is susceptible.

The behaviour towards ionic detergents enables some tentative conclusions to be drawn about the structure of the virus. The resistance to detergent suggests that the virus of foot-and-mouth disease contains no lipid, a view which receives support from the resistance of the virus to the lipid extracting solvents ether, acetone, ethanol and butanol, and by comparison with the viruses of influenza and vaccinia which contain lipid and are destroyed by S.D.S. (There may be a general correlation between susceptibility or non-susceptibility to fat solvents and to detergents whether natural or synthetic). Further, since detergents denature proteins primarily by disrupting hydrogen bonds and salt linkages, it is possible that linkages of this type do not play a significant role in the structure of the virus of foot-and-mouth disease. Linkages of protein to nucleic acid, if these occur, would be expected to be of a co-valent rather than electro-valent character.

Serology

A visiting worker from the Plum Island Animal Disease Laboratory has shown the usefulness of the agar gel precipitin technique for the investigation of virus sub-types. It has been found that there are strains within the seven main immunological types of the virus which differ sufficiently in antigenic composition for them to be classified as sub-types within each of the types. These are significant in relation to vaccination.

During the differentiation of three sub-types by both complement fixation tests and by the agar gel diffusion technique, it was found that the pattern of cross reactivity given by the two methods is similar. By the application of the agar precipitin test to guinea-pig virus and antiserum and to cattle virus and antiserum a similar differentiation of strains could be obtained. These results provide a useful contribution to epidemiological studies since they indicate that agar gel diffusion technique would provide the most convenient method of examining virus strains in current field outbreaks in selected areas, in the study of sub-types, and in the comparison of them with earlier strains.

It was also found that differences in sub-types could not be clearly shown if serum taken from cattle too early in convalescence was used, because cross reactions confused the issue. The nature of these was examined by comparing the serum taken early in convalescence with serum taken later; a difference between the two sera in regard to the specificity and electrophoretic mobility of the precipitating anti-bodies was found.

Pathology

The extensive use which is now made of the unweaned mouse as an experimental animal has already been referred to, and the progress of the disease in this animal has been intensively investigated. A rapidly fatal infection characterised by muscular paralysis can be produced if mice are infected by the intraperitoneal route at one week of age. The susceptibility to infection by this route decreases with increasing age. In mice which have exhibited signs of paralysis of the limbs for a few days,

degenerative changes can be seen with the naked eye in the leg muscles, in other skeletal muscles and in the muscles of the heart. Detailed microscopic examination revealed widespread degeneration of skeletal muscle and slight degeneration of heart muscle in 7-day-old mice; the degeneration of the skeletal muscle was less severe in 3-4 weeks old mice and was accompanied by degeneration of the heart muscle and sometimes of the pancreas; in 5-week-old mice muscle degeneration was slight but there was usually some degeneration and mineralisation of the fat pads behind the shoulders. Some regeneration of muscle had taken place in the two groups of older mice. A vesicle developed on the tongue of one mouse in the group inoculated at 5 weeks. This phenomenon has occurred before, for workers in this country had previously found vesicles on the tongues of several animals in a group of long-tailed field mice which had been inoculated intramuscularly with the virus.

Other workers have shown that in young guinea-pigs also, the virus of foot-and-mouth disease has a marked affinity for muscle and produces extensive degeneration of striated muscle although in mature animals it produces the more typical epithelial reaction, vesicles on the tongue and feet. Similarly in calves the virus may produce rapid death by a degenerative action on striated muscle, whilst in fully grown cattle the disease is characterised by the vesicles on the tongue and the feet. Thus there seems to be a general tendency for the virus to exhibit myotropic characters in young animals and epitheliotropic characters in adults. It has already been mentioned that one of the methods used for modifying the virus is to inoculate it intraperitoneally and to follow this with inoculation into adult mice intramuscularly. This procedure enhances the myotropic and diminishes the epitheliotropic properties of the virus, and probably herein lies the explanation of the better immunity produced in cattle when strains attenuated in this way are injected by the intramuscular route rather than by other routes.

As in cattle, the conspicuous lesions in guinea-pigs infected with the virus of foot-and-mouth disease are vesicles on the tongue, lips and feet. In guinea-pigs experimentally infected at Pirbright lesions of the epithelium have been demonstrated on the prepuce, the ear, the perineal region of males and of pregnant females, the teats of pregnant and lactating females and in the oesophagus, as well as on the tongue, lips and feet. The occurrence of epithelial lesions in sites other than the tongue and feet was recorded as long ago as 1903 but the observations are often forgotten. In cattle, lesions can occur in places other than the tongue, feet, teats and mammary glands of cows; they have been seen for example on the thighs, perineum, anus, vulva, muzzle, nostrils, pharynx, oesophagus, trachea and digestive tract. In the pig, the snout, pharynx, intestine and mammary glands can be affected as well as the mouth and feet.

An interesting new finding in many guinea-pigs was a severe degeneration of the pancreas, which bore a close resemblance to the pancreatic lesions produced in mice by the virus of foot-and-mouth disease and also by several viruses of the Coxsackic group. The virus content of this tissue was very high.

The virus of foot-and-mouth disease usually kills some guinea-pigs, but when the strain has been adapted to the guinea-pig the death rate may be

from 40 to 80 per cent. It seems probable that severe pancreatic lesions are a contributory factor when death occurs within the first four days. In some guinea-pigs, however, pancreatic damage was absent or slight and no lesions which could confidently be regarded as an explanation of the cause of death were seen at post-mortem examination. Invasion of the blood by pathogenic bacteria via the degenerative lesions of the tongue and feet may be significant in causing death.

Factors which might be concerned in determining the location and severity of the lesions found in various epithelial sites in the guinea-pig have been studied. Observations on changes in the susceptibility of the tests during the final stages of pregnancy and during lactation are of interest as they indicate the importance of physiological factors in the development of lesions. It was found, for example, that virgin female guinea-pigs infected with the virus developed lesions on the teats if these, in simulation of normal pregnancy, had been rendered hyperplastic by the action of stilboestrol.

PREPARATION OF EDUCATIONAL MATERIAL

The Institute co-operated with the Ministry of Agriculture and Fisheries in the preparation of a film in black and white for showing to farmers and agricultural audiences; coloured slides for showing to veterinary surgeons in practice and veterinary students; and a coloured film showing the lesions of the disease in cattle, pigs and sheep. The former has been widely shown and the coloured film is in considerable demand from a number of countries and international organisations.

RESEARCH AND THE APPLE INDUSTRY

The chief needs of the apple industry in Great Britain are for improved varieties and for cheaper and more satisfactory techniques for the culture of the tree and for the harvesting, grading, storage, distribution, and utilization of the crop. These needs can be defined in many ways and with varied emphasis upon this or that factor; indeed, each of the phases of production and utilization mentioned would merit extensive review. The present more general review must, therefore, be regarded as something to be challenged in detail in the light of local conditions or of the local interests of grower, distributor, or consumer. It attempts to provide an indication of the fronts on which research is making effective contributions, and more important, to indicate where less than sufficient effort is being deployed.

THE INDUSTRY

Apple industries are well distributed over the suitable regions within the temperate zones¹. Excluding Europe and North America, domestic markets are not large, and the Commonwealth countries, in particular, look to Britain as a substantial and even an essential customer. This has led to very effective, healthy, and smooth collaboration within the Commonwealth as to import and export policy through the medium of the Commonwealth Fruit Producers' Conference and the respective governments. At the conference in London in 1959, it was forecast that world production of apples might well overtake consumption; the total crop of dessert and cooking varieties (i.e. table apples) from the major producing countries was estimated

to be approximately nine million tons per annum, an increase of nearly 40 per cent over the pre-war average. In nearly all the major dessert apple countries in Western Europe, such as the United Kingdom, Italy, Germany, France, the Netherlands, Belgium, and Scandinavia and also in Commonwealth countries, there have been marked extensions in the area under table apples, giving increased potential yields. In Canada and Australia, as in the United States, there has been a reduction in the number of bearing trees ; at the same time there has been an increase in the number of new plantings and some change in their location. Thus in Canada decreased production in Nova Scotia has been accompanied by increased planting in Quebec. In Jugoslavia, Poland, and Russia a wider interest in the possibilities of the apple industry has also been shown.

Production

Production and consumption in the United Kingdom, relative to imports, is shown in the following table². The considerable variation in crop from year to year is noteworthy, as is the substantial increase in foreign imports from 1955 to 1957, mainly from Italy and Argentina. From the Commonwealth, South African apples have been imported in steadily increasing quantity year by year.

	1953	1954	1955	1956	1957
	<i>(thousands of tons)</i>				
Home production:					
Dessert	189	211	192	227	215
Cooking	345	323	208	331	217
Total Table Apples ...	534	534	400	558	432
Table apple imports from Commonwealth	79	93	103	112	104
Table apple imports from other countries	39	50	58	73	76

Although imports have been less than they were pre-war, the consumption of table apples, especially dessert, is stated to be of the order of 25 per cent greater. In home-grown apples there has been an increase in the proportion of two dessert varieties, Cox's Orange Pippin and Worcester Pearmain, and of the cooking apple Bramley's Seedling, probably largely as a result of the post-war policy discouraging the planting of less desirable varieties. Indeed, the predominance of these varieties is likely to increase substantially as the extensive new plantings come into bearing, especially as post-war trial plantings have not yet revealed any new variety that can be widely recommended. Laxton's Superb remains the main late dessert apple, despite the great disadvantage of its markedly biennial bearing. (In passing, it may be noted that the consumer in the United Kingdom still retains his traditional preference for distinct varieties and qualities of apples for dessert and culinary purposes, in contrast to the position in other countries.)

The acreage and production of apples in the United Kingdom, relative to those of other horticultural crops, are illustrated by the following estimates

for 1958 from the Horticultural and Price Statistics Section of the Ministry of Agriculture, Fisheries and Food :—

	<i>Thousands of acres</i>	<i>Thousands of tons</i>
Table apples	128	609
Cider and perry fruit	44	84
Plums, pears, cherries, etc.	68	178
Soft fruit (berries, currants, etc.)	49	86
Brassicas	155	1,035
Green peas	94	140
Dried peas	72	34

The importance of the cider industry, in its own right, is far from negligible. At present North France and Germany are the major cider-apple countries, but extensive replacement with dessert varieties in these countries may in time offer increasing opportunity to the British industry. The cider apple trade, however, is as subject to pressure from Citrus as is the table apple trade, if not more so.

No figures are available for fruit production in gardens or holdings of less than one acre in extent ; such production, though far from inconsiderable in total, is subject to great wastage and, on the whole, is of quite unnecessarily poor standard. Unfortunately this problem of wastage and low standard fruit exists also on many larger holdings, especially where fruit production is not a major interest.

In Britain the need for periodic renewal by replanting is now accepted. Any policy for net expansion of acreage, however, requires to be considered in the light, on the one hand, of increasing world production, due to the coming into bearing of younger orchards in combination with improved procedures in cultivation, harvesting, and distribution and, on the other hand, of increasing costs of labour, storage, and transport, together with the limiting factor of the availability of new land offering the special combinations of soil and climatic factors desirable for top fruit production.

Consumption

The relation between world production of apples and consumption is highly mutable. Consumption might respond quickly to an increase in the at present negligible attempts at education of the consuming public, or to developments in alternative usages for the crop. If these continue to be neglected, however, it is almost inevitable that it will be increasingly affected by competition from the abundant supplies of sub-tropical and tropical fruit reaching our markets.

The community of interest between apple growers in the Commonwealth as a whole has led to effective collaboration in the control of the amount and season of imports to the United Kingdom. The home producer, however, is becoming more and more sensitive to the effect of imports from Europe, especially from Italy and the Netherlands, and from the United States and the Argentine. In the absence of consumer education, American and Continental imports tend increasingly to induce uninstructed consumers to buy, not on eating quality, but on standards of appearance and colour. These standards are often unattainable in commercial production in this country,

especially as the high quality variety Cox's Orange Pippin is not highly coloured.

In 1954, a joint A.I.C./A.R.C. Committee summarised the position as follows:

"Apple production in Great Britain is insufficient to meet consumption save in the autumn months, a position only to be rectified by further improvement in storage techniques and in varieties; were home grown apples, strictly graded and marketed as a standard and thoroughly reliable pack, freely available at competitive prices in the retail markets serving the industrial areas of Scotland, the Midlands and Wales, and were low grade fruit more rigorously excluded from markets throughout Great Britain, the potential market might well be increased considerably.

The major limiting factors to an increase in the consumption of home grown apples would appear to be:

- (a) Unequal distribution of the crop to markets, arising out of the concentration of apple growing in the drier and warmer districts of the South and the additional cost of transport and distribution to the more distant markets.
- (b) The market price relative to that of imported fruits, affected as this is by a variety of factors, such as the cost of production of high quality fruit, transport and handling charges, and the like.
- (c) The inadequate standardisation of pack by the average, rather than the best, apple growers.
- (d) The paucity of effort devoted to the education of the consumer as to the potentialities and characteristics of the best dessert varieties.
- (e) The relatively limited period over which home grown apples can at present be marketed in first class quality.
- (f) The inadequacy of cold and gas storage techniques and capacity."

There is little reason today to modify these words. Most growers would agree that marked improvement would result from active measures by the industry to meet these inadequacies and difficulties, especially through the development and extension of co-operative packhouses, through independent checks on the quality and price of fruit marketed, and through restraint in the marketing of varieties out of their proper season. Market reports, especially from Northern areas, on the standard of grading, packing, and condition on arrival have, in the past, suggested room for radical improvement, but these are matters for the industry itself to remedy.

Objectives

There is no doubt that many growers, as well as advisory officers of the N.A.A.S., would stress as the main needs of the industry:

firstly, to produce far more than the present very limited proportion of top grade fruit to be found in a well grown crop of dessert apples, through improvement in standards of colour, appearance, uniformity of fruit size, and freedom from blemish of the crop,

secondly, to achieve heavier and more regular crops, eliminating the major year-to-year variations in crop size and quality which bedevil attempts at sound planning,

thirdly, to remedy the serious lack of varieties of high dessert quality suitable for marketing in first class condition, and in succession over a long period,

fourthly, to improve storage techniques to permit orderly marketing of existing varieties, and also to improve knowledge of how to grow fruit suitable for long storage,

fifthly, to achieve all this in the face of steadily increasing competition from imported fruits of all kinds, at the same time controlling cost of production (either by increased yields, improved mechanization, or other means) so that the apple retains its position in the family diet sheet, despite the trend to spend proportionately less and less of the family income on articles of food.

Faced with the hard fact that, in the existing state of knowledge, higher standards must mean a great increase in culls from among the large proportion of the crop of "just average" finish or poorer, the grower and distributor alike would welcome the development of any by-product that might offer promise of a working margin of profit on the culls, despite possibly relatively high charges for transport to the manufacturers.

APPLE RESEARCH

Research directed towards the solution of some of these problems has been markedly expanded during the post-war years. There are in England four research stations financed through the Agricultural Research Council (the National Fruit and Cider Institute at Long Ashton, East Malling Research Station, the John Innes Horticultural Institution, and the Ditton Food Investigation Laboratory) that play a major part in research upon the culture, harvesting, and storage of the apple. Related problems of specialized type are under study by Rothamsted Experimental Station, by the National Institute of Agricultural Engineering at Silsoe, and by the Low Temperature Research Station, Cambridge, as well as by the Ministry of Agriculture's Plant Pathology Laboratory at Harpenden. Major responsibilities are also undertaken by the National Fruit Trials, Brogdale, by the Fruit Working Party and by the Experimental Horticulture Stations at Luddington, Efford, Fairfield, and Cawood, all part of the National Agricultural Advisory Service and all collaborating in various ways with the research stations. In addition, the important activities of N.A.A.S. horticultural and specialist officers, and of the N.A.A.S. Fruit Group, deserve mention, particularly in relation to co-operative orchard experiments with growers and regional studies on the control of diseases and pests. Apart from isolated investigations by workers at Bristol and Cambridge Universities, Wye College, only, has attempted to meet the urgent need for detailed study of fruit farm costings, labour usage, and the economics of the many cultural procedures involved in apple production. The A.I.C./A.R.C. Committee quoted earlier took especial note of the importance of increasing provision for this type of work. In Northern Ireland the problems of apple production, mainly of cooking varieties, are investigated at the Horticultural Centre of the Ministry of Agriculture at Loughgall, Co. Armagh, while the possible

development of apple culture in Scotland is being studied at the Scottish Horticultural Research Institute at Mylnefield, Dundee.

The following sections provide some account of the many and substantial contributions made to the health of the industry by the application of research carried out at these various centres. It is important to remember that a small improvement in quality may be more profitable to the grower than quite a large increase in quantity, as has been shown by a recent economic survey⁸.

SIZE, COLOUR, AND SKIN QUALITY

It could not be maintained that all packs of good ("Fancy") market grade, as at present interpreted, would stand comparison in colour, uniformity and skin finish with the best imported fruit, a situation that is in part to be associated with variety and climate rather than defect in culture or grading. The proportion of "Extra Fancy" grade (fruit comparable with the best imported packs) from a well managed orchard only very exceptionally reaches one-quarter of the total and is often much less. This is a problem not peculiar to home-grown apples, but one the importance of which is emphasised by the need for home-grown fruit to compete on the markets with the *best* produce from overseas.

Size, shape and number of fruit

The size and evenness of the apples harvested is materially affected by the number that mature in relation to the size of the tree; by the distribution of the fruit in relation to leaf area, light, and reserves; and by competition between developing fruits. In a good blossom year successful pollination and development of only three or four per cent of the blossoms is sufficient to assure a good crop. Following the gradual drop of unfertilised blossoms, fruitlet number is reduced by a succession of waves of abscission during June and July. Those fruits that remain develop normally until harvest, when the position may be further complicated by rapid shedding, especially under the influence of wind.

Factors influencing *uniformity* of size (and colour) still need further study. Apart from treatments designed to control the number and spacing of fruit brought to maturity, most observations in this field have been made incidentally in the course of the comparison of cultural treatments. Further valuable pointers may be expected to emerge from current work at East Malling on the detailed analysis of cropping in relation to the physiology of flower bud formation, fruit set, and subsequent development of the fruitlet, as well as to fluctuations in the amount and the mobility within the tree of those materials essential for the growth and development of the fruit. Studies carried out at Long Ashton and East Malling on thinning the crop by hand (which makes considerable demands on labour at a time when it is relatively scarce) have shown it to be of limited usefulness ~~unless~~ carried out thoroughly and very early in the season. This has led to attempts to limit the number of fruit buds by reducing the leaf area in the preceding season or, alternatively, to control the number of fruit matured by the use of chemicals to thin the blossom or to influence the number of fruitlets retained. The effectiveness of such measures may be complicated by variations in the severity of the "June" and "pre-harvest" fruit drops which

can, in turn, materially affect the final yield. Although effective control of pre-harvest drop can be obtained by the application of sprays of naphthalene acetic acid, satisfactory control of fruit number and spacing by chemical means has yet to be achieved. So far all methods used have either failed to reach that degree of reliability and general utility that is essential or have markedly increased variability in colour and size of the harvested fruit. It is, however, noteworthy that colour is enhanced by pre-harvest "stick-on" sprays of naphthalene acetic acid and by exposure after picking.

Lighter forms of pruning are attractive both economically and because the flowers produced on the young unpruned shoots blossom later than those on spurs and so provide some insurance against spring frost damage. They do, however, reduce control over the number and position of the fruit but as much of it is well exposed, this probably accounts for the improvement in depth and uniformity of colour that has been found to result.

Such desirable features as better spacing of the fruit, greater uniformity in size and colour, and better colour may yet be achieved earlier through some good fortune in apple-breeding or in the empirical testing of some biologically active chemicals than through the application of the results of fundamental investigations, essential as these are. The aim in breeding should be to produce a variety possessing, together with other desirable characters, that of forming a limited number of highly fertile blossoms well distributed over the tree. Considerable progress has already been made in the management of orchards in such a way as to produce fruit of high quality at economic cost; indeed, but for this progress, apple culture in England would by now be much reduced.

Uniformity of shape is perhaps a lesser problem, but the requisite even development of the tissues of the young fruitlet has been found in some varieties to depend on adequate pollination and seed formation, although this is by no means a general rule. While the development of self fertility is an aim in apple selection, little progress has yet been made and must, in any case, be accompanied by reduction in blossom number. Meantime there is room for considerable expansion in studies on the physiological condition of the tree and of the flower, especially in relation to carbohydrates and nitrogen supply to the leaves. No explanation has yet been found for the differing size, shape, and maturity of the "king fruit" which develops from the terminal flower of the raceme in most commercial varieties in this country.

Important evidence is accumulating that chemicals used for the control of pests and diseases or to amend the mineral nutrition of tree-fruits may be potent, and often unsuspected, agents affecting flower bud formation and the retention and development of the fruitlets after fertilization. Thus, repeated foliar applications of magnesium have been found to influence the number of fruits developed. The nitrogen status of the pollen-parent and the female parent in apples has been shown to affect the efficiency of the pollen and the degree of fruit set respectively. On the other hand, the phenyl mercury fungicides have been found to exercise a depressive effect on flower bud formation in pears that is unassociated with overt damage to the tree and is intensified in wet seasons, while the organophosphorus insecticide parathion has been found to influence the degree of abscission of young apple fruitlets during the development period.

Colour

Even and high colour is determined by variety, by absence of shading, by the nutrition of the tree, and by weather conditions before harvest. The most substantial improvement in colour has been achieved through the development of management systems involving the grassing down of orchards. Originally introduced to check excessive vigour of established trees and to improve their nutrition and the physical properties of the soil, seeded swards or natural swards after clover have become almost general practice in young orchards, and tests are now planned of planting direct in sward.

Skin quality and fruit blemishes

Skin quality is a composite character largely based upon the absence of blemish, whether arising from the attacks of insect or other pests (capsid, codling, fruit tree red spider mite, etc.), from fungus attack (scab, brown rot), systemic virus disease, frost, unattractive russetting or cork formation, bruising, spray deposits, or from undesirable side-effects of the numerous sprays necessarily applied during the course of development.

The effects of pests and diseases are dealt with in a later section, but some of the other factors affecting skin quality deserve discussion here. In some years "frost rings" appear on the fruit; they are due to a lifting of the epidermis of the flower or young fruitlet by ice formation during spring frosts. While extensive investigations at East Malling, Silsoe, and Wisley, assisted by the Meteorological Office and the Fuel Research Station, then at Greenwich, showed that efficient physical protection of orchards against radiation or wind frosts could not be achieved at economic cost, studies of the influence of topography on cold air drainage and katabatic winds have reduced the risk of planting in areas liable to frequent damage. Effective protection, necessarily limited in application, is provided by water sprays, the latent heat of freezing of water as ice forms on the shoots and blossoms keeping them above 30°F and ensuring that the temperature of the susceptible tissues never falls below the critical point of approximately 28°F for a period sufficient to cause damage. Progress has been made in devising automatic sprinklers regulated by the orchard temperature during the hours of frost. Crosses of Cox's Orange Pippin with very late flowering varieties are also being made, to produce apples flowering later in the spring when the risk of damage by frost is considerably less.

Other forms of blemish, including cracking, of the apple can result from the systemic infection of the tree by a virus pathogen. For example, star crack virus can produce characteristic symptoms in the fruit of Cox's Orange Pippin, even though the rest of the tree shows little sign of the disease. The progress of research making possible the elimination of such virus diseases from propagation sources is discussed in the next section.

Bruising during picking and transport is undoubtedly the major source of man-made blemish, far transcending spray damage in importance. With increasing piece-work and the post-war reduction in the size of the trained labour force, avoidance of mechanical damage during picking, during transport on and from the farm, and during grading, storage and marketing, has become even more difficult. While the major commercial fruit shows, and especially competitions involving the judging of packs selected in

the open market, have achieved much, the problem remains a very serious one, particularly with the softer-fleshed varieties. Bulk harvesting procedures⁴, originated in New Zealand in 1952 and since developed in most of the apple growing countries overseas, have been claimed to reduce the amount of damage by bruising as well as reducing labour costs; they may well provide some solution to the problem under English conditions.

CULTURE AND SIZE OF CROP

Crop per acre may be regarded as a function of planting distances and yield per tree, complicated by the requirement for a limited mixture of varieties, usually two, to ensure adequate pollination. The grower's returns, however, are largely affected by the size of the crop in the better grades; the "Domestic" grade of dessert apples has in recent years sometimes failed to repay the cost of transport to market, while save in very limited quantities the culls cannot be disposed of at all.

Some of the most important advances in the culture of the apple in the United Kingdom have been concerned with ways and means of so controlling the vigour and precocity of the trees planted as to assure the grower of early production, while on a long-term basis of utilizing to the full the land available. The very close planting of apple trees on semi-dwarfing or dwarfing stocks, combined with intensive summer pruning, is, however, seldom profitable under post-war conditions, despite the early and heavy yields of good quality fruit that can be obtained.

Large scale apple farming in Southern England began about 50 years ago with an era in which choice of variety, rootstock, site, and cultural treatment, while to some extent influenced by practices developed in the gardens of the great estates, were fluid, not to say haphazard. The early orchards were often planted with a dozen or more varieties, worked on seedling rootstocks or on vegetatively propagated Paradise stocks so mixed, and therefore so unpredictable in effect, that they were but little better. Small wonder, therefore, that the whole trend of research was directed firstly towards enabling satisfactory yields to be obtained from the few varieties outstanding in flavour and quality, and towards establishing improved control of tree growth and uniformity of behaviour.

With the types of pruning then in commercial vogue, inherited from the walled garden, with their high, but then inexpensive, labour requirements and their more restrictive effect upon the scion variety, the selection of suitable rootstocks and their clonal propagation to ensure exact identity from tree to tree provided immediate and spectacular advantages.

Rootstocks

The early investigations of rootstock effect at East Malling and Long Ashton provided the industry not only with rootstocks of known identity, but of closely predictable performance. While almost every aspect of the tree's growth was found to be affected by the rootstock, precocity in bearing and size of tree in relation to soil conditions and climate were brought under a very considerable degree of control. Long-term rootstock trials assured the industry of reliable information. Thus, at East Malling, rootstock trials planted in 1919 are still in being, dwarfing as well as more

vigorous types remaining healthy and continuing to display their characteristic differences. In 1952 five new rootstocks of intermediate vigour were made available to the industry for wider test, while in collaboration with the N.A.A.S., field trials have been set up at 33 different centres throughout the apple growing areas of the South of England. In 1959 a further new rootstock, in the semi-dwarfing range, will be released. (The time required for the production of new material and its proper testing before release is illustrated by the fact that the five new rootstocks originated from the collaboration of the John Innes Horticultural Institution and East Malling Research Station in 1928.) The development of a range of tested clonal rootstocks permitted close planting of mixtures of trees, some on dwarfing rootstocks, precocious and heavy yielding for their size in their early years, together with others on more vigorous rootstocks destined to form the permanent plant after eventual removal of the dwarf trees.

In the post-war period, with its higher costs and greater labour charges, careful trials have been made at East Malling, Long Ashton, and elsewhere, to measure more accurately the effects of lighter methods of pruning and the earlier bearing that can be achieved in this way. These investigations have demonstrated conclusively that earlier economic returns can be obtained from new orchards by light pruning combined with correct choice of rootstock. The lighter forms of pruning thus seem likely to become permanent orchard practice.

Interplanting with early maturing types of trees has received new emphasis from the results of pruning, spacing, and climatological trials, especially in relation to wind, and it seems probable that the industry in England is reaching the point where early yield of new areas will be sought through the precocity, under light pruning, of slightly more vigorous interplants than the dwarfing Malling IX earlier used. These, by their early yield, will compensate for some cultural delay in the bearing of the permanent and more vigorous trees to allow of one, or perhaps two, years additional time for the proper development of a stable and strong framework on these trees. The right choice of rootstock in relation to soil and scion variety is thus regaining adequate emphasis, in perspective with pruning and other cultural treatments.

Little or no work has been done on new apple rootstocks of recent years, save for interest in the possible use of apomictic *Malus* spp. The major lack, in apples as in pears, is of rootstocks capable of assuring adequate mineral nutrition of the scion when grown on alkaline soils. Meanwhile, existing rootstock types are being classified at East Malling in respect of their potential resistance to *Phytophthora cactorum*, a recently identified cause of mortality of mature trees.

Mulches and swards

Turning from the control of tree size and fertility, many studies have been made of the effects on tree growth of mulches and swards as compared with clean cultivation, and of the water requirements of the tree. It has been shown that in young orchards control of the normal summer soil moisture deficit by applications of up to a total of six inches of water increases the growth of the tree and its cropping capacity. Similar, though less well marked, effects result from the supply of additional nitrogen, but

in general it has been difficult to demonstrate economic returns from applied manures, save in the case of potash established years ago, and now of magnesium.

The control of the availability of mineral elements and of water to the tree afforded by the use of mulches or swards, suggests that the interactions of water supply and of the major elements may be of considerable importance. The present trend is to develop orchard research in this field accompanied by study of the equally important aspect of seasonal fluctuations in root activity and especially of the tree's capacity to absorb mineral elements from the soil. Growth, size, and productivity of trees improve with increasing soil acidities down to about pH 5.5; also the usage of farm land many years before planting has sometimes been found to have measurable effects on growth and cropping.

While preliminary studies have suggested that the energy reserves of the tree are sufficient for development at all seasons, thinning experiments have indicated the dependence of fruit size upon leaf area per fruit. Studies in progress at East Malling of the development of leaf area, its efficiency, and the importance or otherwise of leaf damage resulting from the phytotoxic effects of fungicides or insecticides will provide additional information as to the importance of this factor in relation to yield. It is known that for trees of good size some rootstocks, e.g. Malling IV, have a capacity materially to increase the yield per tree of the scion variety relative to other rootstocks. Adequate supplies of potash or of magnesium are also important. A recent experiment on the effect of repeated foliar applications of magnesium sulphate showed that, over a period of five years, increases of over 60 per cent resulted, the effect arising not from differences in the production of fruit buds but from differences in the number of fruits produced. These effects arose from repeated applications; it appeared that one or two foliar applications per season were almost negligible in their effect.

The relative order of importance of the major factors affecting yield per tree in the South Eastern counties, assuming growth on good average land and trees free from virus diseases, would appear to be rootstock, scion variety, available soil moisture, pruning, mineral nutrition, and stem diseases. In replanted orchards, effects carrying over from the previous plantings would also have to be considered, whether these were due to eelworms or other more complex residual effects related to the soil microflora and fauna, or to differences in soil fertility, which are often marked over short distances.

PESTS AND DISEASES

Pests and diseases, as mentioned earlier, may constitute a major source of skin blemish and of fruit loss; equally, the chemicals used may, by the unsightliness or toxicity of the deposit or by affecting the growth and development of the skin tissues, materially affect the value of the crop. The complexity of the position may be illustrated by reference to lime-sulphur which controls scab and mildew at the expense of skin finish; to captan, which is free from harmful side-effects but is not effective against mildew; and to DDT which gives efficient control of codling at the price of potential increase in fruit tree red spider mite. It is to the great chemical firms that the industry must look for that systematic study of whole

ranges of related chemicals that is necessary if improved insecticides and fungicides are to be found. The function of the research stations must rather be to indicate those types of compounds that may repay a thorough examination. Examples of what has been done in this direction in the past are the early studies on phenyl mercury compounds at East Malling; the evidence arising from a joint A.R.C.—Pettar-Ace—East Malling field study that indicated the potential value of the diphenyl type compounds related to DDT in the control of fruit tree red spider mite; the testing of dinitrocaprylphenyl crotonate and related compounds for the control, not alone of apple mildew, but also in part of the fruit tree red spider mite, and the study of thiocarbamates and substituted quinones at Long Ashton.

The majority of the applied problems of the industry involve, in one way or another, abstruse and complex biochemical problems. The following example, which involved collaboration between plant pathologists and biochemists and which offers promise of a new approach to the control of plant disease, is of particular interest. The development of methods for inoculating young leaves of Cox's Orange Pippin with selected strains of the scab organism, *Venturia inaequalis*, combined with the use of injection techniques derived from East Malling's work on mineral deficiencies, has made it possible to study the effect of increasing the concentration in the leaf of certain compounds obtained in the course of biochemical research on the natural constituents of apple leaves and fruits. In this way, increasing, by injection, the concentration of chlorogenic acid within the leaf has been found markedly to increase the resistance to scab of young susceptible tissues, such increase in turn being affected by the nitrogen status of the tissues. The next step, that of testing compounds related to those associated with the natural resistance of the host, together with the study of the effect of nitrogen supply and other factors upon the induced resistance, will, it is hoped, contribute towards the solution of one of the major problems of plant protection, namely the development of non-poisonous systemic fungicides. These could have a great advantage over most existing spray chemicals in protecting tissues which are expanding or developing considerably between spray applications.

Natural resistance of the fruit tissues to infection depends in part upon the development and structure of the epidermis and studies of the waxy protective covering of plants are being developed at Long Ashton. Other investigations, both there and at East Malling, concern the distribution and composition of spray deposits and of the changes that occur after application. These changes involve the chemical and physical structure of the deposit, and the uptake of chemicals from it by the epidermis. Similar studies of copper fungicides have been undertaken by the A.R.C. unit at Wye College, accompanying a major investigation on biologically-active compounds capable of absorption and translocation within the plant—again a field of obvious promise in relation to the search for systemic fungicides.

A drawback of many effective fungicides and insecticides is the high cost of application and, often, of the chemical itself, particularly where, as in the case of scab, mildew, *Gloeosporium*, etc., repeated applications are needed.

Spraying

The post-war years have seen a revolution not only in the chemicals used but also in the methods of application. Spraying by hand lance of several hundred gallons per acre at high pressure has given way to the use of much smaller volumes in the form of fine droplets carried to the tree on an air blast. Early work at East Malling had shown that, provided the mean droplet size was small and the volume applied was insufficient to lead to the droplets running together on the tree, undiluted lime-sulphur could be applied, even to young developing leaves and fruits, without causing the phytotoxic effects commonly caused by this fungicide when highly diluted. Much progress has been made in meeting some of the problems arising in applying this knowledge. The National Institute of Agricultural Engineering has assisted by the production of prototype air blast machines capable of evenly applying as little as 5 or 6 gallons per acre of concentrated spray, while the N.A.A.S. has collaborated with both East Malling and Long Ashton in the field study of problems of efficiency of application and completeness of cover with volumes varying from five to sixty gallons per acre.

The general indications are that, at least at the lower volumes, at a given dosage rate a wide range of variation in droplet size concentration and, therefore, rate of application may be acceptable. Progress with the manifold problems involved in the use of mixtures of sprays, has been less rapid owing to complications of chemical incompatibility and the variability of commercial formulations and adjuvants. Applications either by air blast or from aircraft are necessarily profoundly limited by problems of mammalian toxicity, especially with insecticides.

Timing of spray applications remains a major factor in the efficiency of sprays. The methods developed at Rothamsted for trapping and recording the aerial load of fungal spores have made possible considerable development of studies on the relationship between weather and liability to infection by apple scab and apple mildew. Forecasting has not yet been applied as widely as it has been for potato blight, or for apple scab in the Netherlands; variations from orchard to orchard and within the tree clearly indicate the need for caution in placing reliance on forecasting, particularly when the standard of control must be high. Meanwhile, studies of the liberation in the spring of ascospores, from which develop the first infections, suggest that an important ancillary method of control may be found in DNOC spraying of the dead foliage in which the fungus overwinters.

Development of resistance

So far there has fortunately been little evidence of the development of strains of fungal pathogens resistant to the chemicals used for their control, despite the known occurrence of physiological races of some of the fungi, including the fungus responsible for apple scab. The position is very different with insects, however. The control afforded by chlordane of fruit tree red spider mite, and by lead arsenate of codling moth, show signs of failure, in the first instance because of the development of tolerant strains of the mite and, in the second because of variations in the number and timing of generations of the moth. A number of chemicals, including the natural

insecticide ryania, are under test against codling, while the re-emergent mite problem is being attacked through a study of the development of tolerance, both to chlorbenside and to organophosphorus insecticides. Cap-sid, apple blossom weevil, apple sawfly, and winter moth are all effectively controlled now through the increased efficiency of the newer insecticides available since the war.

Virus diseases

Studies of the virus diseases of apples in the United Kingdom have made great progress in the last decade, and have led to major advances in ensuring the health and productivity of the orchard trees of the future. The recognition of the virus and transmissible nature of the rubbery wood disease, particularly of the Lord Lambourne variety, and of the widely distributed apple mosaic, stimulated vigorous search for sources of healthy material. The development of the Mother Tree Scheme at East Malling has provided nurserymen and growers with tested sources of propagation material. Also the Malling-Merton rootstocks and certain of the older Malling rootstocks now provide virus-free rootstocks for this material. The virus-free trees thus available have given the grower more confidence in his control of the tree's behaviour and productivity. As an example of the unsuspected losses that may be caused by virus diseases, the apple mosaic disease, reported by Long Ashton in 1944, has been shown at East Malling to cause decreases of up to 40 per cent in the cropping of the tree according to the strain of the virus and the apple variety concerned.

Fortunately, present indications are that virus diseases of apple can in very large measure be controlled by rigorous care in the selection and use of propagation material. Meanwhile the search for entirely healthy material of commercial varieties, true to type in all fruiting characteristics, goes on. This search for growing trees free from virus infection can now be supplemented by improved techniques for inactivation of the virus in infected plant material by heat therapy. By this means, propagation material can be produced which shows no reaction with test indicator plants and which is free of the undesirable effects of the virus on growth and cropping.

VARIETIES

Despite the known occurrence of strains of the more valuable dessert varieties, usually distinguishable by greater or less colour, russetting, etc., there has until recently been but little attempt in the United Kingdom to discover whether or not strains vary in yield potential or other important characteristics, such as resistance of the fruit to infection by *Gloeosporium*. The need for heavier and more regular cropping and for reduction in losses in storage has led to an interest in this subject, which is a particularly suitable one for joint study by the National Fruit Trials and by the research stations.

The apple collection of the National Fruit Trials comprises some 1,800 reputed varieties. Some of these are identical; many, as in the case of the Blenheim Orange group, are types morphologically difficult to distinguish but not to be classified as identical. The importance of taxonomic study of this collection is considerable; apart from its value to the breeder,

the collection may well repay as close examination as the new seedlings produced by research stations and others. Bearing in mind that it may take ten years from seed before any preliminary assessment of a seedling can be made and the acreage limitations on the numbers of seedlings that can be fruited, this collection of types, selected under widely differing conditions, merits early and very thorough sifting, especially in relation to eating quality, season, and disease resistance.

An improvement in the range of suitable dessert varieties in the near future must depend upon selection among first crosses rather than long-term breeding. The alternative approach is exemplified by work in progress at the John Innes Horticultural Institution, where a considerable programme of selection for resistance to apple scab is supported by planned back-crossing designed to combine the resistance genes obtainable from related species with the desirable qualities of our best varieties.

In new varieties eating quality and appearance rank first, season and yield come next, but regard must also be paid to regularity of cropping, fruit size, capacity to resist disease, and ability to escape spring frost damage.

STORAGE

It is possible to market Worcester Pearmain up to the end of October, Cox's Orange Pippin until the end of November, and Laxton's Superb until the end of December without special storage facilities. Home production of these varieties, however, is such that storage is essential to orderly marketing and to the proper use of supplies to meet requirements. Unfortunately, Worcester Pearmain is unsuited to storage for more than a few weeks. Cold storage of Cox's Orange Pippin at 37°F can enable well grown fruit to be marketed in good condition until the beginning of January. Gas storage at 5 per cent CO₂, 3 per cent O₂ and at 39°F will extend this until March, overlapping with the marketing of cold stored Laxton's Superb.

Pre-war interest in efficient storage techniques did not revive until after 1950. It was stimulated by recognition of the fact that the considerable plantings of Cox's Orange Pippin in the immediate post-war years would soon pose a marketing problem that would be greatly aided if the storage life of the variety could be extended. Research designed to elucidate the influence of orchard factors, particularly cultural treatments, upon the potential storage life of Cox's Orange Pippin was therefore initiated by the Ditton Laboratory and by Long Ashton and East Malling Research Stations, and later the Imperial College of Science was associated with the work. Pre-war studies had indicated the complexity of the problem, but it was not then anticipated that the major problem would be not the early senescence of the fruit; or blemishes associated with cultural or climatic conditions such as bitter pit; or those associated with storage, such as scald and internal breakdown of various types; but the development in store of rots due to pre-storage infection with two species of *Gloeosporium*.

The early work on this disease at Long Ashton has, since 1953, been followed by further work at all four centres. Three means for partially controlling the disease have been found: viz. the removal of infection

foci by pruning, the use of late sprays of captan, and improved management of the orchards under swards. The study of the complex of orchard factors which influence storage life has been greatly complicated and retarded by the *Gloeosporium* problem. However, recent work at Wye College on the inhibitory effects on the disease of the vapour of (2:4:5-trichlorophenoxythio) trichloromethane holds promise, not only of considerable direct benefit to the industry in the control of the disease, but also of aiding the general study of storage problems by allowing research to progress unhampered by the incidence of these rots.

Pre-war apple storage techniques represented a triumph of planned empiricism associated with fundamental studies. It seems unlikely that substantial extension of the period of economic storage can be expected in the near future from fundamental studies alone. Empirical studies on a small scale are therefore now being undertaken by the Ditton Laboratory, in addition to fundamental work, to extend the range of varieties for which precise storage procedures can be recommended, and to investigate the possibilities of more flexible regimes than are at present available.

Besides fundamental studies on the senescence of stored apples there is need for an index, even only an approximate one, of the likely relation between the condition of the apple at picking time and its optimum storage treatment. Such studies will require still further collaboration with growers. Growers from all over the South East of England already supply fruit for storage experiments and are thus playing a part in the attempt that is being made, at East Malling and Ditton, to correlate orchard treatments with storage life. For further progress it seems very probable that research workers may have to call on the aid of co-operative packhouses in providing additional information.

BY-PRODUCTS

The cider industry, mentioned here only in passing, should not be regarded as providing a potential market for cull fruit of table apples, even though a proportion of such fruit is used for this purpose. A market for cull and poor grade fruit would be of the greatest value to the industry, but the prospects, as reviewed by the Development Commission⁵, appear poor. However, it is noteworthy that in the United States 33 per cent of the total sales of apples during 1956-57 were to processing industries, mainly canning. In Canada the average has recently been about 25 per cent; in Australia from 10 per cent to 15 per cent; but in Tasmania, with its more intensive apple production, it has exceeded 30 per cent on occasion. Production of manufactured apple products thus appears to be significant only in those countries where loss of markets, or local over-production, is a major factor in the prosperity of the industry.

¹ Oxford Economic Atlas of the World. Oxford University Press. 1955.

² Commonwealth Economic Committee. Fruit. H.M.S.O. 1958.

³ WALLACE, D. B. and PLAISTER, A. J. Apple Production. Rep. Univ. Cambridge Sch. Agric. 56, 1958.

⁴ TIDBURY, G. E. The Bulk Harvesting of Orchard Fruit. Bur. Hort. Plant. Crops, E. Malling, Dig. 1. 1958.

⁵ Development Commission. A Survey of Agricultural, Forestry and Fishery Products in the United Kingdom and their Utilisation. H.M.S.O. 1953.

BLOOD TYPES IN CATTLE

From the beginning of the century it has been known that all members of a species do not have the same sort of blood. In 1900, goat's blood had been repeatedly injected into other goats, and antagonistic substances were found to build up in the recipient. These combined with the donor's red blood cells and hastened their removal and destruction, though the recipient's own red cells were not affected.

It was already well known that bacteria which invaded the human and animal body would stimulate the production of counteracting substances which combined with the bacterial cells and helped in their removal. These substances moreover, were specially adapted to the type of bacteria which initiated their production. The ability to discriminate between the red blood cells of individuals then fell into place in the progressive and vigorous subject of immunity.

Methods already existed by which the specialised substances, or antibodies, could be used to discriminate between and identify types of bacteria which were otherwise indistinguishable. Ten years later, by the use of these methods, it was possible to recognise individual differences in the blood of cattle.

The importance of these discoveries, from which arose many of the modern procedures of blood grouping, was overshadowed by the observation, also made in 1900, that antibodies were present in the blood of most normal human beings. In the past, many physicians had been tempted to treat disease and injury by transferring blood to the patient from a healthy person. The reports of disorders and even fatalities which had however attended these attempts, must have served as a constant reminder that the knowledge required for successful treatment was still missing. This new discovery revealed the incompatibility by the simple process of mixing some red blood cells from one person with a drop of blood serum from another, whereupon it was found that some people possess antibodies which unite with and clump together the red blood cells from another person. This could only happen to those red cells which had a special substance, an antigen, with which the antibody could combine. An important prerequisite for successful blood transfusion was therefore to select a donor whose red blood cells would not be clumped together when they became mixed with the patient's blood and tissues.

The antibodies were of two sorts, anti-A and anti-B. The antigens of the red blood cells with which they react when mixed are also named A and B correspondingly. The four types of blood to be found are: A red cells together with the antibody anti-B; B red cells with anti-A; AB red cells with no antibody; and O red cells with both antibodies.

Any person could now be assigned to the group of those with blood like his own, and his Blood Group was a label conveying this important information. With blood transfusion as routine treatment in many parts of the world, the term "blood group" retains this significance to the present day.

The study of blood groups in cattle and other animals was greatly influenced by these momentous findings but it was over 25 years before a

return was made to the implications of the individual differences demonstrated in 1910. In the interval, although the demand for blood transfusion for animals was small, some comparative observations were made on cattle, perhaps chiefly out of curiosity. The simple technique which had proved itself in man was adopted, and a search was made for similar patterns of antibodies and red blood cells upon which they reacted.

The results were disappointing. Reactions between the red cells of some animals and the blood sera of others were certainly found, but they did not fall into the attractively systematic pattern of the human groups; most of the reactions were weak, and it was generally concluded that bovine blood groups were not as well developed as the human.

The early work on goats and cattle, however, had brought out hidden differences of compatibility. The antibodies which detected these differences were not present to begin with but were built up in the recipient as a result of repeated injections of red blood cells. The same phenomenon soon became familiar also to surgeons whose patients required for their treatment repeated transfusions of blood, and the antibodies which could develop only in response to transfusions of foreign blood now demanded as vigilant attention as the ready made antibodies anti-A and anti-B.

THE MODERN APPROACH TO BLOOD GROUPS IN CATTLE

A few men of vision saw that the study of blood groups need no longer be confined to the field of therapeutic blood transfusion but would provide a means, hitherto lacking, of studying the genetic constitution of man and animals. The use of antibodies to detect otherwise unsuspected differences in micro-organisms had been developed as a method of the nicest discrimination. In the human blood groups the red cell characters had been shown to be clear-cut and genetically determined, and were quite simply present or absent. Furthermore they gave no outward sign of their presence and could not therefore be subjected to conscious selection.

So to the geneticist these red blood cell characters as such are no longer of prime importance. They merely reveal the action of a particular gene. Nor are the antibodies by which the red cells are told apart thought of as anything more profound than testing fluids. Blood grouping now in fact becomes the most promising tool for the recognition of genetic factors, acting on the simple interpretation that one gene determines one antigenic blood character which is detected by the corresponding type of antibody.

This method of recognising the effect of a single gene will permit definite statements to be made about the genetics of individual animals. At present, a large number of distinct blood characters is known in cattle and most of them are detected by reactions with antibodies. Variant forms of other blood constituents, e.g. haemoglobins, are being disclosed by the use of biochemical and biophysical methods, and these give every indication of being equally precise instruments for the detailed genetic analysis of cattle. The future occurrence of each distinct type of antigen or haemoglobin in every animal is fixed at the moment of conception according to the laws of mendelian genetics, and this is also true of certain serum proteins which are under investigation today.

The antigens

These are the substances in red blood cells which combine with antibody or stimulate the production of antibodies after injection. The A and B antigens distinguishing the human blood groups have already been mentioned. Red cell antigens are part of the structure of the red cell and all those which have been fully studied have been found to be of a polysaccharide nature. They cannot be removed from or obscured in the intact red cell. There is, as yet, no convenient method of storing the red cell antigens after an animal has died. They cannot be detected by any chemical methods: they are recognised and identified only by the use of the particular antibodies with which they combine preferentially. More than 30 different antigens are now widely known and as many more are probably known in particular laboratories.

The antibodies

The antibodies with which they react are composed of a normal protein constituent of the blood, the molecules of which, in some unknown way, have become specifically adapted to the corresponding antigen. It is not possible to make antibodies by any chemical method. They can be elaborated only within the animal and, with few exceptions, only under the stimulus and in the presence of the corresponding antigen. Most antibodies can be conveniently and effectively stored in the frozen state for years. Wherever possible, antibodies of different specificity are separated from each other and used independently as testing fluids.

All except one of the antibodies in common use are produced by the repeated injection of blood from one ox into another. Rabbits, sheep and goats are also successfully used as producers of certain antibodies. The recipient does not make antibody to those antigens of the injected blood which it happens to possess itself, but its antibody forming tissue may be stimulated by the antigens it lacks to make the antibodies to which they correspond. With a few exceptions, red cell antigens are erratic in their ability to stimulate antibody in an apparently suitable recipient; and an accurate and systematic prophecy of the nature of the antibodies which will be produced is not possible at present. It is possible to forecast which antibody will *not* be made in response to a given injection. There are no independent and absolute standards of composition or purity for antigens and antibodies as there are for chemical reagents.

When antibody is mixed with red blood cells the molecules will combine with any antigens with which they correspond. A useful analogy is a lock which can be operated by the key which fits it. The analogy is a good one, for many locks can be operated by keys which were not intended for them but which have a closely similar shape. In some antigen-antibody reactions there is the same lack of exact specificity, i.e. of one-to-one correspondence, for some antibody preparations will react with antigens which have a slightly different genetic control, but these "cross reactions" do not occur between antigens controlled by widely differing genes. This lack of precise and rigid specificity is well authenticated by fundamental immuno-chemical studies.

The firm chemical combination of red cell antigen with the corresponding antibody takes place within a few minutes of mixing and is

invisible. The secondary effects of the combination, of which the clumping of red cells is only one, can be brought out by a variety of techniques, the proper choice and execution of which are essential if the results are to have any value.

The Haemoglobins

There are two sorts of haemoglobins in adult cattle—the “fast” type and the “slow” type. In Britain, only the Channel Island and South Devon breeds have both sorts. They are distinguished not by antigen-antibody reactions but by the different rates at which their molecules migrate when under the influence of an electric current. Results obtained by this method may need biochemical corroboration or confusion with foetal haemoglobin which is normally present in calves may lead to an erroneous conclusion.

The Serum Proteins

During the last three years, several different types of bovine serum have been found when samples are subjected to a method of analysis similar in principle to that described for the haemoglobins. The chemical nature and the genetic control of these differences are being investigated in several laboratories. They promise to be a particularly valuable addition to the armament of the blood type laboratory.

The Genetical Background

Each type of antigen, of haemoglobin and of serum protein has its own special genetic control. The influence of dozens of distinct genetic factors, “genes”, can be traced in a couple of drops of ox blood. The way in which these genetic factors are transmitted from generation to generation, and the particular influence which each has on the blood character it controls must be carefully investigated for each newly discovered blood type. Some are inherited independently of the others, but many are transmitted together in groups or clusters called “systems”. Each “system” has two or more genetic factors and the most complex has more than twenty. Each animal receives only two genes belonging to any one system, one from each parent. The effect of one gene may overshadow the other, or both may be detectable. When the tests on a blood sample disclose the types of antigen, haemoglobin or serum protein present, it is helpful further to identify the two genetic contributions of each system, that is to type the genes from a knowledge of their effects on the blood characters.

THE BLOOD TYPE SYSTEMS

1. The Haemoglobins

With respect to the haemoglobins, cattle are of three types: those with haemoglobin of the faster type, those with the slower, and those with both. The genetic type can be determined by inspection, as the cattle with both haemoglobins have inherited the gene for the fast from one parent and the gene for the slow from the other.

2. The serum proteins

The most recent review (for which independent confirmation has not yet been published) is that three different genes govern six different types

of serum proteins. Each animal receives two genes which may be alike or different and the three like and the three unlike pairs give rise to the six possible types which have been recorded.

3. *The antigens*

The antigens are put into 10 or 11 systems. The J system is the only one regularly associated with a naturally occurring antibody—the exceptional case referred to above. The antibody has a strength that fluctuates under genetic and environmental, particularly seasonal, influences. The antigens of this system, of which the second has only recently been discovered, begin in solution in the plasma, the red cells absorbing the antigen only secondarily to become reactive to the antibody.

Five systems called the D, L, M, Z and Z' are each represented by two genes one of which is inert, while the other controls the production of an antigen described by the same symbol. For each system, cattle which inherit an inert gene from each parent lack the antigen on their red cells. These cells will not react, therefore, with the appropriate test fluid. If one inert and one active gene are received, however, the red cells give a positive reaction, usually indistinguishable from the reaction given by the red cells of cattle which have received the active gene from each parent.

The FV system also has two genes, but in this case the antigenic product of both can be recognised. All cattle have one or both of these antigens, so that each animal is in one of the three classes F+ V+, F+ V-, F- V+, and no animals of the type F- V- are found. The AH locus has four genes one of which is inert, and the expression of another variable. The remaining two form a sub-type where the presence of one is conditional on the other. The SU system has at least four genes and the C system has at least eight, in each of which subtypes occur.

The B system has been said to be the most complex in the whole of genetics, with a large number of genetic factors influencing the antigenic properties of the red cell. For the study of the B system, 20 testing fluids are commonly available and it is reported that eighty are currently used in the most advanced laboratory. By using the standard serological techniques to the limits of their powers of resolution many cross reactions between these testing fluids can be found which expose an intricate variety of antigenic relationships.

Many of the other reactions given by red cell samples are serologically distinct but are commonly seen to occur in certain associations. These grouped reactions can easily be shown to have a genetic basis in the form of a so-called "complex locus" with many alternative sets of genes. As in the other systems the observed reactions are a mixture of the separate effects of any two of these sets.

No theoretical framework has yet been devised which would allow the existence of hitherto unsuspected associations to be predicted. By genetical and serological methods however, the characteristics of more than one hundred of these sets have been found and catalogued. With other information it is often possible to identify more or less accurately the two sets of genes which are responsible for the serological reactions observed.

The prevailing view is that the individual genes within these sets are not to be thought of as the grapes on a bunch which have a separate existence, but rather as faces of a polyhedron each of which represents one aspect of a more complex structure.

APPLICATIONS OF BLOOD TYPING

1. *Association with production*

In poultry it has been shown that birds of certain blood types are more productive than others and it is financially worth while for the big poultry firms to take advantage of this fact. The existence of so great a variety of blood characters in cattle suggests that they also confer or reflect some selective advantage. Statistical analysis has suggested that one blood type is associated with a higher milk yield, and another with a depressed yield. The possibility that advantage can be taken of these in improving production is being explored in several parts of the world.

2. *Association with disease*

Some of the haemoglobin variants in man are directly associated with certain anaemias, but this is not so in cattle. Statistical analysis also shows that human beings of particular blood groups are more likely to contract certain diseases. This has not yet been found in cattle, but it should be remembered that medical history is less well documented in cattle, whose length of life is deliberately restricted.

3. *Haemolytic disease of the new-born*

This occurs in man, horse and pig as a result of antibodies of the mother so damaging the offspring's red blood cells that anaemia and other disorders result. A similar condition has been suspected in cattle but it is either very rare or it exists in a hitherto unidentified form.

4. *Linkage with other factors*

Some cattle are carriers of deleterious or unwanted genetic factors. These genes are recessive and are not distinguishable unless two such genes are inherited by the same animal and until it reaches the age at which they make their effects apparent. If a blood type gene were found to be very closely linked with the gene for horns, for example, it would be possible to determine which calves of a bull known to carry the factor had received it by identifying those which had necessarily also received the blood type gene which acts as a marker. If the linkage were looser than this, further genetical information about the bull would be required to make a useful forecast. As more and more marker genes are recognisable, so is the probability increased that useful linkages will be found.

5. *The spread and distribution of genes*

Many of these blood characters have different frequencies in different breeds and herds. Indeed, the breed of the animal from which a blood sample was taken can often be recognised by serological reactions alone. These frequencies can be used to assess the degree of inbreeding in a population of cattle. An interesting study has demonstrated that Shorthorn cattle whose breeding was once concentrated in a few animals, have a reduced variety of blood types in consequence.

It is also important to find out whether this technique will measure the rate at which genes spread from the bull producing herds throughout the breed. Information of this nature will help to illustrate some of the results of breeding policy which cannot fail to be of interest.

6. *Twins*

Blood typing is increasingly applied to twin cattle to distinguish two egg twins from those which might have their origin in a single egg, and also to diagnose the freemartin. One egg twins, widely used for genetical and physiological research, have no genetic differences. They are identified by the absence of differences in characters which are known to be influenced by heredity, such as coat colour and hair character. Blood group methods are independent of and additional to these external inspections. If the members of a twin pair differ in one or more blood characters they are undoubtedly of different genetic composition.

About nine tenths of the heifers born twin to a bull have malformed genitalia which render them sterile. They are called freemartins and can usually be diagnosed by professional examination. Where no signs of genital abnormality can be detected, however, typing blood samples from the heifer and her co-twin can, in most cases, confirm the veterinary opinion that she will be reproductively normal. The anatomical basis of the development of the freemartin condition is an open connection between the blood circulations of the two fetuses which allows some of the precursors of the red blood cells to wander from one to the other and there settle down. These cells and their descendants produce red blood cells which can only be of the type which corresponds to their genetic origin, and this will usually differentiate them from the red blood cells of their host. The mixture persists throughout the life of the twins, each of which continues to live with red blood cells of two different types. The detection of the mixture in the laboratory may however present difficulties particularly where its existence is not suspected.

7. *Blood transfusion*

There is no doubt that, if its safety could be assured, blood transfusion would be eagerly adopted by veterinary surgeons in many parts of the country, particularly for the treatment of the haemolytic anaemia of redwater.

The early work, using the techniques of human blood grouping, suggested that naturally occurring antibodies were weak and perhaps insignificant in cattle but recent investigations, using techniques adapted for the purpose, show that about a quarter of all cattle have detectable antibodies called anti-J. These are weak in the young animal and show a seasonal fluctuation, but they are often as strong as those which have to be treated with respect in man. The red cells with which these antibodies react, however, have taken up their antigen J from the plasma in which they are bathed. When blood of this type is transfused into an anti-J recipient, the antibodies may be neutralised by the soluble antigen before the red cells themselves can be attacked, and this may be protective. Although clinical signs of distress are uncommon with a first injection of bovine blood, a second transfusion from the same or different donor,

if given a week or more later, has elements of danger and must be conducted with caution. Veterinary practitioners wisely refrain from depending on a simple cross-matching of the recipient's serum with red cells from the proposed donor. The red blood cells of some cattle will not clump together even when mixed with quite powerful antibody. This would engender a false sense of security and a blood transfusion given in consequence might jeopardise the patient's chances of recovery.

It is unquestionably true that our knowledge of the clinical importance of blood groups and blood transfusion for cattle is very inadequate. Research in this field would surely be rewarding, and the next step might well be an assessment of the value of radioactive tracers as indicators of the fate of the transfused red cell.

8a. *The clarification of doubtful parentage*

Methods of blood typing cattle have been developed primarily to support the accuracy of breeding records by detecting those which are in error. The procedure requires an examination of the antigenic characters of the blood of the animals concerned; the haemoglobin and serum protein types have not yet been used in these exclusion tests.

The laws of heredity of the red cell antigens are known; for example, the antigens present in an individual must also be demonstrable in one or both of its parents. When this is so, the stated parentage may be correct. When any antigen is absent from the blood of the animals alleged to be the parents, a mistake must have been made. The aim of the most usual investigation, however, is not to detect errors but to assist in identifying the sire from among those bulls by which the dam was inseminated. If all but one are excluded there is no objection to accepting that one as the sire. The occurrence of these cases of doubtful parentage depends on three factors, first, whether cows returning to heat will be served by the same or a different bull, second, the interval between the services; and third the variation in the length of the gestation period, which is influenced by breed, age of dam, season of the year, sex and sire of calf. When two bulls were used and the service interval was less than fifteen days, there is no possibility of predicting the paternity from the expected calving dates alone.

Thus the blood types of bulls, dams and calves can be recorded and used by scientifically minded persons to clarify questions of parentage. They can also be used to indicate possible errors in pedigree records and ultimately, to provide an unassailable and repeatable identification mark for an individual animal. Whenever a dispute arises, the scientific evidence of blood typing by which it can be clarified should be presented by the person making the laboratory tests, who must ensure that the records can be validly compared. On such occasion blood samples from the animals concerned should be re-examined simultaneously under identical conditions using specialised extra techniques to exclude all known causes of blood typing errors.

8b. *Standardised reagents and international notation*

The testing fluids or reagents which are used to detect antigens are prepared by each laboratory according to its own standards. In general,

new batches are not perfect replicates of previous ones and no way is known by which this could be ensured. Annual technical conferences have been held for a number of years at which the reagents prepared and used in different laboratories are compared. These are essential for keeping the names of the reagents in line with each other so that technical information can be exchanged and statistical data compared.

Cases of disputed parentage, however, involve individual animals and cannot happily be settled by statistical evidence. It is certain that for some years to come the responsibility for the evidence by which these problems are solved must remain in the hands of a single laboratory. An internationally acceptable blood type certificate is not possible in the present state of knowledge. With blood samples from the same animals, however, a second laboratory could be called in to confirm the report of the first.

FUTURE WORK

There are two problems of immediate practical significance. The first is the expansion of the materials and techniques which already exist in Britain for the provision of a blood typing service: such services exist in other countries and there is no technical barrier to founding one in Britain. The second is to make blood transfusion safe and helpful in veterinary practice.

Looking further ahead, it is possible to foresee uses which might well follow from progress in understanding the physiological and genetical bases of blood types. Not all such uses can be foreseen, but two seem promising. Antibody response is already known to be influenced genetically and more detailed knowledge could offer the prospect of developing improved techniques for breeding strains of animals resistant to particular infections. Further, the more detailed the analysis of the specific genes affecting blood constituents the nearer we shall be to forecasting the economic value and health of an animal from its own and its parents' blood types.

METABOLIC DISEASES OF RUMINANTS

There are three principal kinds of condition that occur in ruminants which are classified as metabolic diseases: (1) those that are characterised by a disturbance in the mineral composition of the blood; (2) those characterised by an abnormal accumulation of the metabolic products known as "ketone" bodies in the blood and often by a reduction in the concentration of blood sugar; and (3) those characterised by acute indigestion accompanied by a gross distension of the rumen by gas.

The two illnesses of the first category occurring in cattle are milk fever and grass tetany. The milk fever syndrome is well known by dairy farmers and the condition occurs usually immediately after parturition and unless treated death is probable. Grass tetany has several other names—lactation tenany, grass staggers and hypomagnesaemic tetany—but all of

the names are misleading as it is not confined either to grazing or to lactating animals and the expression "tetany" does not adequately describe the prostration and convulsive seizures that characterise the condition. The only common feature is that that concentration of magnesium in the blood is abnormally low. Although both kinds of illness occur in sheep a close study of them has not been made so that for the present discussion is best confined to cattle.

The second group of conditions include "acetonaemia"—now called ketosis—of dairy cattle, and twin lamb disease or pregnancy toxaemia of ewes. These conditions are characterised by loss of appetite, lethargy or stupor. The byre may have a sweetish smell due to the presence of acetone in the urine and acetone appears in the milk, the yield of which is much reduced. In cattle it occurs usually within 14–28 days after calving, about the peak of lactation, but it may occur earlier after calving, especially if there is some other abnormality such as failure to expel the foetal membranes. It can also occur at calving as a complication to milk fever. The condition in ewes occurs mostly in animals with twin or multiple pregnancies during the last month of gestation and its incidence can be related to the method of feeding and to climatic variation that may prevent the animal feeding or that causes other kinds of stress. The death rate in ewes in a bad season may be serious but no figures are available to show the exact extent of the loss caused to sheep farmers in this country by this condition. It occurs in all countries where sheep are kept and is especially troublesome in Australia.

The third category consists of the disorder known as "bloat" in which the rumen is distended with a foaming mass of food in which the gas is trapped. This is the common condition seen in animals grazing early summer or second growth autumn pastures, especially where clovers are extensive. Cattle grazing lucerne are liable to bloat and this form is described in most countries of the New World. There are, however, other forms of bloat in which foam formation does not seem to occur; an example is the bloat that is sometimes found in young calves when weaned early. "Feedlot" bloat occurs in the United States in yarded animals fed on a high starch ration and foaming of the rumen contents is characteristic of this type of bloat. Bloat is not common in sheep except when grazing lucerne but in South Africa, where this is practised, it is a troublesome problem.

Recent surveys of the incidence of illness in dairy cattle in Surrey, Berkshire and Wiltshire given in Table 1^{1,2} show that, with the exception of milk fever, metabolic diseases are not numerically particularly important in these areas. Mastitis was revealed as the principal cause of loss to dairy farmers in these counties and during the years 1950–54 its incidence in the herds under survey increased. On an average 40 per cent of all illness reported—excluding illnesses associated with calving—was due to mastitis in contrast to about 8 per cent represented by acetonaemia, grass tetany and bloat combined.

TABLE 1

*The percentage incidence of disease in dairy cattle in Surrey,
Berkshire and Wiltshire*

			1950-51	1951-52	1952-53	1953-54
Total stock in survey	...	...	3,452	4,966	5,984	4,879
Mastitis	...	...	8.1	7.1	10.1	14.5
Digestive disturbances	...	...	5.0	2.2	4.3	2.6
Foul foot	...	...	3.7	1.4	1.4	1.2
Accidents and injuries	...	...	3.2	2.0	1.8	2.5
Respiratory disease	...	...	0.6	2.8	1.0	1.2
Johne's disease	...	...	1.0	0.8	0.9	0.8
Genital disease	...	...	(0.2)*	(0.9)*	0.5	1.2
Acetonaemia	...	...	0.8	0.7	0.6	1.2
Bloat	...	...	0.6	0.7	0.5	1.0
Grass tetany	...	...	0.1	0.5	0.4	0.5
Clinical tuberculosis	...	...	0.3	0.2	not recorded	
Other illnesses	...	...	1.4	1.2	1.8	2.5
Total incidence	...	...	25.0	20.5	23.3	29.9

* Transferred from data given in Table 2 to conform to the method of reporting for the years 1952-53 and 1953-54.

Illness or other disturbances associated with parturition are given separately in Table 2^{1, 2}.

TABLE 2

*The percentage incidence of disease in dairy cattle associated with parturition in
Surrey, Berkshire and Wiltshire*

			1950-51	1951-52	1952-53	1953-54
Total parturitions in survey	...	...	3,515	5,041	6,074	4,983
Difficult calvings	...	...	2.0	1.6	1.4	1.5
Still births	...	...	6.8	7.1	3.3	3.1
Abortions	...	...			2.4	3.3
Retained placenta	...	...	3.3	2.5	2.5	2.3
Milk fever	...	...	2.8	1.6	2.5	3.7
Total incidence	...	...	14.9	12.8	12.1	13.9

The total number of parturitions given in Table 2 is greater than the total number of animals in the survey as a proportion of cows calve twice in a period of a year. The figures in both tables show the percentage incidence of cases reported irrespective of whether an animal was affected more than once. Milk fever represented nearly 20 per cent of the total. During the four-year period the number of cases given in both tables is equivalent on an average to 38 per cent of the animals in the survey and about one-eighth of the cases were due to the four conditions—milk fever, acetonaemia, grass tetany and bloat. When the relative importance of these four conditions is compared it is found that 50 per cent were due to milk fever, 18 per cent to acetonaemia, 15 per cent to grass tetany and 9 per cent to bloat.

MILK FEVER

Nearly thirty-five years ago this condition was found to be characterised by a decrease in the concentrations of both calcium and inorganic phosphorus in the blood plasma and it was shown that the majority of cases responded to an injection of a suitable calcium preparation^{3, 4}. It is well known that once a cow has had milk fever she very often develops it at subsequent parturitions. It is unusual for milk fever to occur at the first parturition and it is most frequent at the third, fourth and fifth parturition. It is more frequent in high-yielding than in low-yielding cows⁵. The two features that need emphasis are the increased incidence with age and the susceptibility of individual animals.

During normal parturition depressions in the concentrations of calcium and inorganic phosphate occur in the plasma while a slight rise occurs in the concentration of magnesium. The organic phosphorus fractions of the blood behave in the same way as the inorganic fraction. These changes in calcium, phosphorus and magnesium return to normal about 3 to 10 days after parturition. It is of considerable interest that the extent of depression in calcium and phosphorus concentrations in the blood increases with the age of the cow, which is in keeping with the fact that the incidence of milk fever also increases with age, and indicates that milk fever is the result of an exaggeration of changes which normally occur at parturition and onset of lactation^{6, 7}.

At parturition the cow has to supply the necessary calcium for the milk without allowing the concentration of calcium in the blood to fall to a dangerously low level. Milk contains about 4.5 g calcium per gallon while the blood of a 1,000 lb. cow contains about 3.7 g. The two sources from which the necessary calcium may be drawn are the food and the bones.

It is a normal process in ewes during pregnancy and lactation for some calcium and, correspondingly, some phosphorus to be withdrawn from the bone of the mother in order to supply the foetus and later the milk even when there is an abundance of these elements in the food. The changes are most marked in the vertebrae, pelvis and mandible^{8, 9}. At the end of lactation recalcification of bone occurs in two months if the dietary supplies of calcium and phosphorus are adequate. For the ewe 5 g of calcium and 2.5 g of phosphorus per day are adequate for this purpose.

It is reasonable to assume that some mobilisation of bone salts also occurs in the cow during pregnancy and lactation as it does in the ewe; indeed it is likely to be greater owing to the relatively larger quantity of milk secreted. The fact that the incidence of milk fever increases with the age of the animal is compatible with the concept which is generally believed that bone salts are less readily mobilised with increasing age. The hormone of parathyroid gland is concerned with mobilisation of calcium and phosphorus from bones, and its action in promoting excretion of phosphate by the kidney is well recognised. In addition there is some evidence that it increases the absorption of calcium from the gut. The relation of this gland to the absorption and to the release of calcium and phosphorus from the bone, especially at parturition, and the effect of age on this relationship deserve further attention in dairy cattle.

A method of preventing milk fever that has been widely advocated is the process of "steaming up" the cow during the period before parturition. This system which consists of increasing the feed during the last two months of pregnancy presumably allows the animal to receive sufficient calcium in the food to meet the requirements when lactation starts. The administration of large doses of vitamin D, 10 to 30 million units daily for three to eight days prior to calving, which increases absorption of calcium from the gut, has been recommended in the United States.

GRASS TETANY (lactation tetany, grass staggers, hypomagnesaemic tetany)

This condition occurs most commonly in cows soon after they are put out to grass in the early summer but it also occurs in stall-fed animals especially during the late winter months. It is not confined to lactating cows and all classes of cattle may be affected and also sheep. Because of the varying circumstances under which it may occur this disorder has been described as being either the "spring" type, the "winter" type or the "out-wintered" type, the latter term being used to describe the tetany occurring usually in February or March in store or beef cattle maintained out-of-doors throughout the winter with only moderate supplementary feeding¹⁰. A marked decrease in the concentration of magnesium occurs under all circumstances and a decrease in the calcium concentration of the plasma also occurs in 75 per cent. or more of cases recorded^{11, 12}.

A seasonal fluctuation in the concentration of magnesium in the plasma is recognised in cattle maintained out-of-doors all through the year and a depression occurs during the winter months which reaches its lowest level during December¹³. A relationship between this and the temperature and weather has been observed, mild weather being associated with higher values. It is also well known that there is a decrease in the concentration of magnesium in the plasma of housed cattle when these are turned out to graze in the early summer and the extent of the decrease varies greatly from animal to animal.

The low level of feeding of cattle in Norway during the War led to a well-defined increase in the incidence of metabolic diseases generally¹⁴ and the cattle fed indoors with paper pulp as part of the source of energy in the ration were particularly liable to develop tetany. Restricted grazing of cows in New Zealand has led to a reduction in the magnesium concentration in the plasma and more severe measures, exaggerated by the injection of thyroprotein, have induced tetany¹⁵. Bad weather with high winds and rain may lead to a self-imposed restricted food intake and so predispose to tetany. The circumstances in which the condition may arise are so varied that no complete explanation in terms of animal husbandry is possible.

Magnesium deficiency as such has been studied in rats and calves. It can be produced by feeding a ration containing 18 mg of magnesium/kg to growing rats and death may occur in 12 to 15 days. The first signs of deficiency are hyperaemia of the skin, loss of hair, nervousness and diarrhoea, the faeces often containing blood. The animals recover from this phase but growth ceases: later they develop convulsive seizures that may terminate in death. The bones lose about one-third of their magnesium. Little or no magnesium is lost from the soft tissues but calcification may

occur, particularly in the kidneys. Rats fed on food with a low content of magnesium, 40 mg/kg, do not die although they show the initial signs of deficiency. The magnesium concentration in the plasma, however, drops to about half its normal value. The adequacy of the magnesium content of the food is influenced by the calcium content and when the calcium content is high then rats are more susceptible to lack of magnesium^{16, 17, 18}.

Magnesium deficiency in calves is similar to that described in rats except that the early signs are absent apart from occasional diarrhoea, and loss of magnesium in the faeces is nearly doubled when this occurs. The first characteristic sign of deficiency is a change in the carriage of the head and of the ears. The animals become hypersensitive, superficial reflexes are exaggerated and sudden noises or disturbances may cause a convulsive spasm; this is in keeping with the earlier observations on rats. Calves appear to need much more magnesium in relation to their size than rats and calves fed less than 2 mg magnesium/100 ml of synthetic milk food (about 166 mg/kg dry matter) become depleted and die. The changes in the magnesium content of the bones are similar to those occurring in rats. A progressive decrease in the concentration of magnesium in the plasma occurs and convulsive seizures occur when this value is less than 0.7 mg/100 ml. The normal range for this value in calves is considered to be 2.0 to 2.5 mg/100 ml¹⁹. A depression of the calcium concentration occurs in the plasma²⁰ of calves receiving an inadequate quantity of Vitamin D.

There seems little doubt that the concentration of magnesium in the plasma reflects closely the quantity of magnesium available to the animal and it is well known that in many cows this concentration decreases when they go out to grass in the early summer. The decrease in urinary excretion of magnesium when grass is fed varies considerably from animal to animal. Stall-fed cows fed on typical winter rations consume from 16 to 33 g of magnesium daily; when fed on cut early summer grass their consumption is less, being from 10 to 16 g daily^{21, 22, 23}. This reduction in intake does not seem large enough to account for the observed changes in the blood and urine unless the magnesium in grass is not absorbed so easily as the magnesium of fodders and other winter foodstuffs.

The manurial treatment of pastures is known to affect the incidence of tetany: in Holland it is most common on pastures that have received heavy dressings of nitrogenous and potassic manures. The incidence increases with the quantity of potassium applied²⁴. Recent work in Eire²⁵ confirms the findings in Holland although in England²⁶ heavy nitrogenous dressings alone have increased the incidence. Magnesium and calcium in herbage are depressed to a small extent in plots dressed with potassium²⁷, but as recovery of the temporary decrease in the concentration of plasma magnesium occurs without any increase in the magnesium content of the herbage it seems as if some other factor must also be concerned^{25, 28} in producing the low concentration of magnesium in the blood.

The occurrence of the convulsive syndrome does not seem to be closely related to the concentration of magnesium in the plasma and it is a common experience that some animals can tolerate a low level of circulating magnesium without showing signs of illness while others develop convulsive seizures when there is a higher concentration of magnesium in the

blood. Whatever is the final cause that precipitates seizures there seems to be no doubt that the application of magnesium dressings to pastures or the incorporation of adequate amounts of magnesium in concentrates gives good protection against the condition occurring^{25, 26} so that a practical means of prevention is available.

ACETONAEMIA IN CATTLE

This condition, also called "ketosis", is the least well-defined clinical entity of the metabolic diseases. The name implies an abnormal accumulation of the ketone bodies— β -hydroxy-butyric acid, acetonacetic acid and acetone—in the blood. This may occur as a complication to many conditions or simply as a result of fasting. Ruminants are especially prone to this condition. In cattle it occurs a few days to a few weeks after calving and is most frequent when milk yield is at its peak¹². It is more common in cows of the second, third and fourth lactations. Frequently a mild form occurs within a day or two of calving.

A seasonal variation in the concentration of circulating ketone bodies in the blood has been observed and stall-fed cows in March have a higher level than grazing cows in July without clinical signs of illness²⁹. Clinical ketosis is characterised not only by an increase in the circulating ketone bodies but usually by a depression in the circulating glucose in the blood.

Fasting produces a greater degree of ketosis in heavy-yielding lactating cows or pregnant cows than in non-pregnant cows or in cows with a moderate milk yield³⁰. Loss of appetite, therefore, whatever its cause, may be an important factor in the development of the condition.

Ketosis in a biochemical sense means that the products of metabolism of body tissues or of absorbed nutrients are not being oxidised rapidly enough to prevent the synthesis of excessive quantities of ketone bodies. As the principal compound concerned— β -hydroxybutyric acid—is itself oxidised in many organs of the body, its accumulation implies that the rate of synthesis exceeds the rate of utilisation or excretion. The materials that produce major quantities of ketone bodies are the fatty acids which are derived from the metabolism of body fat or from the digestion and absorption of dietary fats; certain amino acids derived from proteins also make an important contribution. These materials are all eventually degraded within the body into a simple 2-carbon compound, acetic acid, which is then, in combination with a complex molecule (coenzyme A), transferred either into the body's oxidative system of metabolism or to a synthesis of ketone bodies. If the oxidative system is impeded or inadequate then excess combined acetate goes to form ketone bodies. The oxidative system which is centred about a complex cycle of reactions is derived from carbohydrate or protein sources. There appear to be two main schools of thought concerning the genesis of "ketosis". The one considers that the oxidative pathway becomes inadequate and the other that ketosis is due to excessive formation of acetyl coenzyme A. The former theory implies that addition of carbohydrate derivatives to the metabolic pool will cure the condition, the latter regards excessive production of coenzyme A as probably due to a disturbance of the endocrine control of this process.

The digestion of the ruminant is peculiar in that fermentation in the rumen accounts for a large part of the total digestion. The principal

products of fermentation are acetic, propionic and butyric acids, and these are rapidly and continually absorbed into the blood stream³¹. Acetic and butyric acids, which are the building blocks of long-chain fatty acids, are known to be ketogenic, while propionic acid, by supplying the necessary structures for oxidative metabolism, favours oxidation rather than ketone body synthesis. Under these circumstances the quantity of propionate formed in the rumen in relation to the other two acids is important. This varies with the ration and although some propionate is always formed its quantity is boosted when starch- or sugar-rich foodstuffs are fed^{32, 33}.

The successful use of "cortisone" and "Hydrocortisone" acetate with cows suffering from severe ketosis has been reported and is taken to mean that decreased activity of the gland concerned with the production of these or similar hormones may be concerned. These glucocorticoids favour the utilisation of carbohydrate and inhibit the degradation of fat³⁴. It is known that during parturition there is a large increase in the concentration of 17-hydroxy-corticosteroids circulating in the blood of cows and that the concentration falls later to a level that is slightly lower than it was before parturition. The effect, however, varies a great deal and has no relation to subsequent milk yield³⁵.

It is not possible to offer any complete explanation of the origin of ketosis. It may be that the mild types of acetonæmia can be prevented or controlled by careful attention to the food and to the comfort of the animal. The avoidance of circumstances that distress the animal is also important. Repeated large doses of sodium propionate have been used in the United States in treating acetonæmia with reported success. This provides the natural source of carbohydrate for the cow. Other compounds such as citric acid, glutamic acid and the alcohol—propanol—should theoretically be even more effective providing they can be absorbed from the alimentary tract without being destroyed. Glycerol has been advocated, and lactic acid and succinic acids should also be effective. The use of compounds such as these may relieve the ketosis as such but if the condition is due—as it may be in acute forms—to a pathological condition of the adrenal or other endocrine glands, they may be only temporarily effective. Nervous or other forms of stress, however, may be concerned and under these conditions suitable treatment on the lines indicated should help to tide the animal over until equilibrium is restored.

PREGNANCY TOXAEMIA IN SHEEP

This condition in sheep seems to be essentially the same as ketosis in cattle, but is confined to the pregnant ewe, particularly to the ewe carrying twin lambs or triplets, and occurs when the lambs are growing rapidly "in utero" at the end of pregnancy. Ketosis has been produced simply by suddenly starving pregnant ewes during the last period of pregnancy³⁶. The ewe, therefore, is most susceptible when the demands upon her are at a maximum and the situation is comparable to that in the cow where the maximum demand is reached as lactation approaches its peak. The fact that the last stages of pregnancy in ewes occur at the lean end of the winter when, in addition, bad weather (including snowfalls) is likely gives

some support to the concept that lack of food and environmental discomfort are concerned in causing the condition.

Fat ewes seem to be more liable to develop pregnancy toxaemia than animals in a lean condition. It is known that slow progressive underfeeding from the early days of pregnancy, although raising the concentration of circulating ketone bodies and depressing blood sugar, does not necessarily produce the clinical condition. It is the rapid change from a high level of nutrition to a low one that seems to be most liable to cause ketosis or pregnancy toxaemia. Although in need of food the ewes refuse to eat. Recently it has been shown in large scale field trials that keeping ewes lean during the early stages of pregnancy and providing supplementary feed during the later stages reduces the incidence of pregnancy toxaemia to negligible proportions³⁷. Undoubtedly the endocrine system is involved in a way that is not yet understood. Sudden curtailment of food is not always followed by the clinical disease and other forms of stress are probably involved. It is of interest that successful parturition is followed by rapid recovery.

BLOAT

This is usually associated with leguminous pastures but it has been reported from purely grass leys³⁸.

In those types of bloat associated with excessive foam formation in the rumen contents it is not clear why foaming becomes excessive in such a spasmodic, unpredictable and rapid way. No relationship has been found between the composition of the food—whether it be early summer pasture or a starch-rich fattening ration—and the sudden onset of bloat. There is always a certain amount of foaming in the rumen of animals on lush pastures but the circumstances that allow it to get out of hand are not yet understood. Plant proteins, when expressed from the plant and aerated under conditions that are similar to those that occur in the rumen^{41, 42}, form a strong stable foam and may therefore contribute to foam formation in pasture bloat. The gas is produced as a result of rapid fermentation especially of soluble sugars which are present in young green grasses and also as a result of the liberation of carbon dioxide from the bicarbonate that enters the rumen in the saliva—which is secreted in copious amounts during feeding—and from the blood in exchange for the organic acids produced as a result of fermentation in the rumen and directly absorbed from that organ.

Antibiotics were first used in the control of bloat in the United States³⁹. Partial suppression of fermentation brought about by administering from 100,000 to 500,000 units of penicillin prevents foaming and this is one way of controlling an outbreak of bloat⁴⁰. The penicillin has to be administered by hand to each individual cow every three days during the bloating season and, consequently, it is not likely to be popular as a prophylactic measure unless cows can be induced to eat the necessary penicillin in a feed. In any event repeated dosage appears to induce the presence of resistant bacteria in the rumen as its preventive action disappears with time. This form of treatment is best kept in reserve to deal with acute outbreaks that cannot be otherwise controlled. Individual cases are best treated by the administration by mouth of vegetable or mineral oils which break the foam. If these are given before the animal is in an acute state rapid recovery can be expected.

Spraying the pasture with emulsions of vegetable oils has been effective in New Zealand in preventing bloat. This is only applicable where strip grazing is practised⁴³.

Most of the work on bloat has been done in South Africa, the United States and in New Zealand where bloating is a greater hazard than it is in this country. The factors that are conducive to foam formation have been studied, especially in New Zealand, and at present attention is being given to the possibility that natural antifoaming agents, such as plant fats and pectins may be destroyed in the rumen with the result that foaming suddenly becomes excessive. The bacteriological population of the rumen is not always stable and unaccountable variations are known to occur, and variations such as these may be the root cause of the sudden onset of bloat.

Studies with identical twin pairs of cattle⁴⁴ have shown that certain pairs are more prone to bloat than others which indicates that some inherited factor is concerned.

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QUALITY IN MILK

The broad subject of quality in milk embraces bacteriological quality, compositional quality, and, closely linked with the latter, nutritive quality. These three aspects are reviewed in turn.

BACTERIOLOGICAL QUALITY OF MILK

One of the most noteworthy advances in milk production in this country has been the rapid increase in the number of producers holding "Tuberculin Tested" licences. At the present time about 80 per cent of the volume of milk produced in England and Wales comes from farms holding T.T. licences, and a further 10 per cent from "attested" (T.B. free) herds not yet covered by T.T. licences¹. Ten years ago only 13 per cent of milk came from producers in England and Wales who held T.T. licences. To qualify for such a licence the producer must, amongst other conditions, produce milk of such a standard of cleanliness as will pass a prescribed test. The methylene blue test has been used for this purpose in England and Wales since before the war, but more recently, with an increase in the routine testing of raw milk supplies, the methods of testing have come up for critical examination². The clot-on-boiling test is gradually being recognised as the most accurate test for keeping quality, and since a reliable time/temperature compensation scale can be applied, it is well suited for routine grading purposes throughout the year. In Scotland and Northern Ireland the colony count and coliform tests are applied as statutory tests, but whilst they may provide additional information, their application is costly and time-consuming.

A statistical analysis³ of the effect of methods of milk production on the results of bacteriological and keeping quality tests has shown that of the many factors of milk production technique investigated only the sterilization of utensils and the cooling of the milk showed any correlation with the keeping quality.

The Milk & Dairies Regulations, 1949, permitted for the first time the use in England and Wales of approved chemical agents as an alternative to the use of boiling water or steam in the final treatment of the equipment, and their use is now widespread. Sodium hypochlorite and the more recently developed combined detergent sterilizers, based on available chlorine and

quaternary ammonium compounds, are subject to approval by the Ministry of Agriculture, Fisheries and Food, jointly with the Ministry of Health.

Three tests have been used for the evaluation of chemical sterilizers for dairy farms; a can test as a screening test, a surface film technique as a laboratory test, and farm trials to give a comparison between the bacteriological quality of milk produced using the standard control material (sodium hypochlorite with an alkaline detergent) and the test material. A comparison of the results of farm trials with those of evaluation by the can test indicated a very close relationship. It is now considered possible⁴ to dispense with lengthy and costly farm trials and rely on can tests to evaluate new formulations, provided short user trials are carried out to ensure that they give no trouble on the farm.

Before approval all materials are tested for bactericidal efficiency at the National Institute for Research in Dairying, and the user can rely on approved products to cleanse effectively his equipment, provided that the officially recommended methods are followed⁵.

Not all farmers and their dairymen have learned how to apply the basic principles of hygiene and cleanliness, and the time and skilled labour needed to cleanse adequately modern milking equipment are not always available. To overcome the latter difficulty, more reliable methods of cleaning have been the object of recent work. The success of immersion cleansing for direct-to-can milking⁶ involving the use of caustic soda, and stainless steel equipment designed for a simplified cleaning process, has assisted the farmer to produce milk of good keeping quality more easily. Attention is now being given to the cleansing of the more complex types of pipeline milker which reduces the manual labour of getting milk from cow to churn, but which may present problems where steam is not available for sterilizing the plant.

"Circulation cleaning", where detergent sterilizer solutions are circulated throughout the plant after milking, is in practical use, but should be regarded as being still in the experimental stage, as many plants at present cannot be maintained in a satisfactory bacteriological condition. It appears that this method will only save time and effort, and maintain the required standards of cleanliness for long periods, if plant is design specifically for circulation cleaning, preferably with some form of automatic control of the circulation system.

The process of bulk milk collection is already an established procedure in several areas of England and Scotland. It is clear that where bulk milk collection is efficiently organized, and the procedure laid down is followed, considerable economy in labour will result, and the bacteriological and keeping qualities of the milk can be highly satisfactory.

The handling of liquid milk has undergone considerable changes. The number of producer/retailers is falling rapidly and over 95 per cent of all milk for liquid consumption is heat treated, mainly by pasteurization⁷. The Joint Milk Quality Control Committee has sought to provide a uniform standard of acceptance for supplies for the liquid milk market. A similar standard is applied under the Scottish Milk Test Scheme. The amount of milk rejected in England and Wales is small and rarely exceeds 1½ million gallons per annum (0.1 per cent. of the total milk sold from farms). The

rejection test is based on the assessment of keeping quality as raw milk, and although it has been shown⁸ that most pasteurized milk of indifferent keeping quality originates from bulked raw milk of poor quality, the keeping quality of individual supplies of raw milk may bear little relation to its keeping quality after pasteurization. The rejection test does indicate the majority of farms where dairy hygiene is neglected, and on balance it would seem that a test to detect poor keeping quality raw milk may well do a great deal of good in raising the level of palatability, and perhaps even keeping quality of pasteurized milk.

A number of alternatives to the ten minute resazurin test has been suggested as rejection tests, but so far none has proved better, either in reliability or ease of application.

Despite the improvements of past years in the bacteriological quality of ex-farm milk, and advances in processing techniques and plant hygiene, pasteurized milk as delivered to the consumer is still subject to disagreeable faults due to spore-forming organisms which are resistant to heat. One of these is *Bacillus cereus*, which produces the fault known as "Bitty cream", characterized by the appearance of floating particles on the surface of tea and other hot liquids. Following heat treatment, and under suitable temperature conditions, the spores germinate and give rise to fresh crops of rapidly multiplying bacteria. The presence of but a few spores in a bottle of milk, under the right conditions, gives rise to the fault. Spore forming bacteria of the type responsible for bitty cream have a widespread occurrence in nature, and may gain access to milk even under the best conditions of production and processing. The number of spores in milk is not related to keeping quality or to total colony count⁹, and it thus follows that the solution of the problem does not lie only in more stringent methods of hygiene on the farm or at the creamery, though this may lead to improvement. The only practical way of preventing the development of the fault is to ensure that milk be kept as cold as possible (below 10°C) at the dairy, during distribution, and in the home¹⁰. This is only rarely achieved during the summer months. Investigations carried out in Scotland⁴⁵ have shown that 87 per cent of samples of milk obtained from individual farms and creameries contained fewer than one cell of *B. cereus*/ml. The main source of the organism was found to be milk cans which had been allowed to stand for a long time before being properly washed and "sterilized".

The temperatures required for the destruction of spores are relatively high compared with those used for pasteurization¹¹ and although spores may be destroyed by the prolonged high temperatures used in the "in-bottle" process of so-called "sterilized milk", changes such as browning and undesirable flavours are produced which are not acceptable to many consumers. In recent years interest has been revived in heating milk to temperatures well over 100°C for only a few seconds. These Very High Temperature (VHT), or Ultra High Temperature (UHT), treatments have an extremely lethal effect on micro-organisms, but have little effect on flavour, colour and nutritional properties¹². Experiments carried out on milk heavily inoculated with extremely resistant spores have proved conclusively that UHT treatment at about 135°C can completely destroy

all bacteria in market milk¹³, but milk so treated will soon be recontaminated unless it is dispensed into sterile containers under aseptic conditions.

Filling machines of the type currently used are quite unsuitable, as they are difficult to sterilize and to maintain in a sterile condition. Furthermore, bottle washing machines cannot be expected to ensure sterility¹⁴. The engineering problems concerning these processes are engaging the attention of research workers throughout the world. Methods of sterilizing bottles by steam under pressure have shown promise¹⁵ and attention is being paid to the use of alternative containers, such as cartons or plastic bottles.

UHT milk is homogenized during processing and may not be acceptable to those who judge milk quality by the cream line. However, the advantages of prolonged keeping quality and simplification of distribution may well make the project attractive to both producer and consumer.

COMPOSITIONAL QUALITY OF MILK

The results of recent investigations into the many factors which influence the composition of milk will be briefly described.

It is well known that the breed of cow exerts a marked, general effect on the composition of the milk. Within the last few months, additional and fully representative data on breed differences have been published. The Milk Marketing Board of England and Wales¹⁶ obtained the following averages for the milk of large numbers of single-breed herds as received at creameries during the year ending September, 1958: Ayrshire, 3.81, 8.72; Friesian 3.62, 8.65; Shorthorn 3.70, 8.75; Guernsey 5.54, 8.94; Jersey 4.90, 9.10 and Red Poll 3.71, 8.78 per cent. fat and solids-not-fat respectively.

The composition of herd milk in Scotland, also, has been determined on the farms of the seventeen recording districts¹⁷. The breed averages for the year ending August, 1958, were Ayrshire 3.89, 8.71; Friesian 3.61, 8.61 and "other breeds and crosses" 3.88, 8.82 per cent fat and solids-not-fat.

It must be emphasized that these are average values, and that the composition of the milk of the individual animals and herds within each breed covers a wide range which is of partly environmental and partly genetic origin. That fat percentage and milk yield are heritable characteristics is well established, but information on the inheritance of the non-fatty solids within breeds has been lacking. For this reason, an extensive investigation involving the detailed analysis of the milk of 500 pairs of dams and daughters of the Ayrshire breed regularly for a lactation has been carried out in Scotland¹⁸. By the method of dam/daughter correlations, values of approximately 0.5 were found for the heritability of solids-not-fat and protein percentages and of 0.35 for lactose and fat percentages. The Milk Marketing Board is using a different approach and testing for fat and solids-not-fat the milk of groups of daughters of Ayrshire, Friesian and Shorthorn bulls used at A.I. centres in England and Wales. The Ayrshire data have been studied¹⁹ and a heritability value of 0.65 found for solids-not-fat and of 0.5—the generally accepted value—for fat. The comparatively high heritability found for solids-not-fat percentage shows the advantage, where improvement of solids-not-fat is

desired, of selecting breeding stock on the basis of the solids-not-fat performance of the individuals.

The composition of milk varies with the age and stage of lactation of the cow and with the season of the year. The data collected in Scotland for the investigation of inheritance outlined above¹⁸ provided valuable information on the effect of these three factors on the total solids, fat, solids-not-fat, total protein, casein and lactose contents of Ayrshire milk²⁰. The effect of these, and other factors on the fat and solids-not-fat of individual cows and herds has been thoroughly discussed also in a bulletin presenting a five-year study of six Friesian and three Shorthorn herds in the South and Midlands of England²¹.

The fat and solids-not-fat percentages are highest in the first lactation: the fat falls slightly with advancing age by about 0.2 by the fifth or sixth lactation, but the solids-not-fats falls appreciably—by about 0.4 by this time. The later fall is an unfortunate natural effect, since an unusually high proportion of deep-milking cows in their fourth or later lactations will seriously lower the quality of the herd milk.

The fat and solids-not-fat are relatively high for the first two weeks or so after calving, and then fall rapidly. The fat is lowest at the 10th–12th week and then rises steadily. The solids-not-fat content is lowest at about the sixth week and remains low until the 4th–5th month of pregnancy when it rises sharply—but cows not in calf show a continuing fall. This effect of interval after calving will markedly influence the composition of the herd milk if many of the cows calve at one period of the year or remain barren.

The fat content of milk follows a simple seasonal trend, being highest in October and November and lowest in May and June. Seasonal changes in solids-not-fat are more complex and vary in different parts of the United Kingdom: in general the level is relatively high in October, falls steadily to a minimum in March and April, rises rapidly in May to a peak in June, and falls again, but to a lesser extent, in July and August; but in south-east Scotland and East Anglia the lowest levels may occur in the late summer months.

The health of the cow's udder, as would be expected, affects the composition of her milk. Not only clinical mastitis, but also sub-clinical infections—which may persist for months—reduce the fat, solids-not-fat and lactose contents of the milk of the infected quarters. In herds with a very high incidence of mastitis milk of poor composition may be due to this factor alone, but recent investigations^{22, 23} have shown that in the great majority of herds the overall effect of mastitis on milk composition is likely to be small. Moreover, after the elimination of an infection, spontaneously or by treatment, from a quarter, there is a rapid, although not always complete, recovery in milk composition in the same lactation and complete recovery in the next.

Much progress has been made in the investigation of the influence of changes in the amount and type of food given to the cow on the composition of her milk. Research and field experience have shown that too low an intake of roughage, such as hay or silage, can seriously reduce the fat content, and an important series of papers has dealt with this

subject. A significant fall in fat percentage, without change in milk yield, occurred when the amount of hay in the cow's ration was limited to 8 lb. per day or less and concentrates were increased to maintain the normal feeding standards²⁴. The fall in fat was not affected by the level or type of protein in the ration²⁵, but it was particularly marked when the hay given was finely-ground or when the concentrates contained a high proportion of flaked maize²⁶, a pre-cooked food with its starch in a readily-digested form.

Depression of fat percentage was associated with changes in the composition of the fat, in the consistency of the cow's rumen contents, and in the products of the rumen digestion²⁷ such as a decrease in the proportion of acetic acid in the volatile fatty acids of the rumen contents. The authors attributed the secretion of milk of low fat content by cows on diets lacking the physical condition of "fibrousness", but not necessarily lacking fibre as such, to the reduction in the amount of acetate available to the mammary gland for the synthesis of milk fat. Recent experiments have demonstrated that the administration of sodium acetate to the cow largely restores the fat content²⁸.

In farming practice, low fats may occur in this way under winter stall-feeding conditions, in spring if the herd is grazing lush, young herbage and given excessive amounts of concentrates, and in autumn if large amounts of leafy kale are fed along with concentrates and with but little hay, silage or straw.

Since the early 1940's investigations in several countries have shown that, contrary to earlier belief, rations deficient in energy (starch equivalent) drastically reduce the solids-not-fat content of the milk, and falls of up to 0.5 in the percentage, due mainly to a fall in the milk protein, have been observed. A shortage of protein in the ration is less detrimental. Within the last few years the effects of feeding the cow at energy and protein levels well above the normal standards have been assessed. Increasing the starch equivalent of the total ration to 25-40 per cent. above the standard usually increases the solids-not-fat percentage by 0.1-0.2, but sometimes by less^{29, 30, 31, 32}. Increasing the protein in the ration^{29, 30, 33} has no effect. It is now well recognized that the plane of nutrition of the cow, in terms of energy, has determining effect on the solids-not-fat and protein contents of her milk, and she should be well fed at all times if the compositional quality of the milk is to be maintained.

The seasonal variations in the composition of milk may prove, in due course, to be largely of nutritional origin. The rapid rise in solids-not-fat (again due to a rise in milk protein) which frequently occurs when the dairy herd is changed from winter feeding to spring pasture has been found to be consistent with an increase in the plane of energy nutrition^{34, 35}.

Further advances in our knowledge of the influence of feeding will depend on fundamental biochemical studies of milk composition in relation to rumen metabolism. This subject has recently been discussed³⁶, and suggestions were made for the metabolic routes by which the different proportions of volatile fatty acids produced in the rumen from different types of feed may affect the secretion of either milk fat or protein. When solutions of fatty acids were infused into the rumen of lactating cows³⁷

acetic acid increased the milk yield and the fat percentage ; propionic acid had no effect on milk yield, depressed the fat percentage and specifically increased the protein percentage.

NUTRITIVE QUALITY OF MILK

It is now generally accepted that the special nutritional importance of milk in the diet lies chiefly in its content of good protein, calcium, riboflavin (and other members of the vitamin B complex) and vitamin A. National Food Survey data show that the total milk consumed (i.e. as liquid, condensed and dried milk and cream but not cheese), of which 95 per cent is liquid milk, provides some 50 per cent of the total calcium in an average household diet, some 40 per cent of the riboflavin, some 20 per cent of the total protein and over 10 per cent of the thiamine and vitamin A. These nutrients with the exception of vitamin A are associated with the solids-not-fat fraction.

The nutritional importance of milk may possibly be more clearly illustrated³⁹ by the contribution of 1 pint of milk to the daily allowances of nutrients recommended by the British Medical Association⁴⁰ for a man doing medium work. The pint would provide him with about one-fifth of the allowance of protein and thiamine, half that of riboflavin and over four-fifths that of calcium.

As clearly stated, most of the liquid milk consumed in this country is heat-treated in one way or another and it is pertinent to consider the effects of such treatment on the milk nutrients. The long-established treatments, Holder pasteurization, High temperature-Short Time (HTST) pasteurization and sterilization in-bottle, were examined in this connexion some time ago and it was found that pasteurization, particularly by the HTST method, has little deleterious effect apart from reducing slightly the thiamine content³⁹. However, the drastic heat treatment of in-bottle sterilization destroys about one-third of the thiamine, injures to some extent pyridoxine (vitamin B₆) and reduces slightly the value of the milk proteins³⁹. In this respect, the UHT treatment presents marked advantages, the process causing no more change than pasteurization⁴¹. However, until and unless aseptic bottling of UHT milk is commercially developed the now necessary resterilization in-bottle leads to a product that offers nutritionally no advantage over in-bottle sterilized milk⁴¹.

Apart from those arising from heat treatment, losses of nutrients may also occur in milk before processing and during transport and delivery. They may be due partly to the destructive effect of adventitious metals from the dairy equipment, particularly copper, but are mostly caused by undue exposure to light. The effects are broadly speaking threefold: destruction of vitamin C (ascorbic acid), destruction of riboflavin and production of off-flavours. Vitamin C is particularly vulnerable and though milk as it comes from the udder contains useful quantities of it, milk as it reaches the consumer is not a dependable source. This fact in itself is not of great moment since vitamin C in the usual mixed diet is predominantly supplied by green vegetables and fruits. Off-flavours induced by exposure to sunlight may be quite important, leading as they do in some countries to rejection of milk through unpalatability. In this country, fortunately, such off-flavours, which are due to oxidation of the fat are

rare and do not present a problem. Losses in riboflavin, which probably amount to some 4-6 per cent.⁴² are also not grave but they do underline the fact that it is careful handling of milk that allows the consumer to derive full benefit from modern methods aimed at providing a safe and palatable milk of high nutritive quality.

The content of B vitamins in milk is largely independent of the diet of the cow since a sufficiency of them arises in the normal processes of bacterial activity in the rumen. The cow must, however, obtain the fat-soluble vitamin A from the ration to put it into milk. She derives it from carotene, the yellow vitamin A precursor present in green fodders. The general farming trend since the war has been towards greater use of pasture and of silage and kale. A survey carried out during the war at the National Institute for Research in Dairying has established the seasonal fluctuations in the vitamin A and carotene content of bulk milk from depots throughout the U.K.⁴³ A similar survey now in progress has shown that on certain farms increased use of green fodders during stall feeding has reduced the winter trough in the content of these two constituents, but that over the country as a whole there has been little change from the picture obtained some 15 years ago.

The significance of milk in human nutrition is discussed in a recent Food and Agriculture Organisation booklet⁴⁴ which, together with the publication already mentioned³⁹, deals exhaustively with nutritional problems of milk quality studied in this country.

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BIOMETRICAL GENETICS AND PLANT BREEDING

BIOMETRICAL GENETICS

The genetic differences upon the study of which classical genetics has been founded display their effects in a clear and unambiguous way. To take one of Mendel's own characters as an example, his tall plants varied in height but all were about 6 ft. high or even taller. His short plants must also have varied, but they were only 18 ins. or so in height. Thus tall and short were always distinct: the shortest tall was always clearly taller than the tallest short and he could assign every plant to one or other class with certainty. He was thus enabled to infer with confidence the existence of a gene (as we should now call it) T for tallness and another, t, alternative in inheritance to T, for shortness. Wherever he saw a tall plant he could recognise the action of a T gene, and wherever he saw a short one he could recognise t. The only complication was that a plant receiving T from one parent and t from the other, being therefore of constitution Tt, was tall and indistinguishable from a TT plant obtaining T from both parents. Thus when both genes are present T masks the effect

of t , which is thus said to be "recessive", T being described as "dominant". Even this is not a serious complication, for TT and Tt plants are easily distinguished by a simple breeding test. The relations between character and genetic constitution are simple and easily ascertained.

Such simple genetic differences are to be found in all living species, plants, animals and man alike. And sometimes in our domestic plants and animals they are of practical importance, as affecting disease resistance or some other important character. However, most of the variation with which the plant or animal breeder has to deal is of a different kind. It does not divide the plants or animals into sharply distinct classes from which simple genetic differences can be inferred, but gives a graded expression of the character stretching smoothly between wide limits, the middle type being the most common. This we can see for example in the variation of stature in man, or in the variation of virtually every character, like yield and quality, of commercial importance in our domestic plants and animals. Now, this *continuous* variation is heritable, at least in part, just as is the discontinuous variation of classical genetics illustrated by tallness and shortness in peas. Furthermore its inheritance depends on genes carried on the chromosomes and transmitted from parent to offspring in just the same way as the genes of classical genetics. The difference is that the genes of continuous variation have individually small effects, but they occur and act in swarms or systems the members of which have similar effects on the character. Thus large differences come about where the member genes of a system pull in the same direction, reinforcing each other in their effect on the character. They can also balance out one another's effects where they pull in opposite directions and so give intermediate expression of the character. And as there are many genes in the system, many combinations of reinforcement and opposition are possible so that the character can show many grades of expression, and the same grade of expression can be produced by many different genetical combinations especially in the middle and most common ranges of the character.

Thus in continuous variation the relation between character and genetical constitution is very complex. The individual genes can no longer be identified and followed in inheritance by their effects, for these are neither large nor specific. Indeed expression of the character depends on the number of genes acting in the two directions rather than on the specific genes present. The classical techniques of genetics, which depend on following individual genes, can obviously no longer be used. New methods are needed. It is the aim of biometrical genetics to supply them and to develop the genetical theory of these complex polygenic systems upon which the new analytical methods must be based.

Since with continuous variation the individuals cannot be assigned to easily recognisable classes with simple genetical meanings, biometrical genetics cannot proceed by the use of ratios in the way that classical genetics does. Instead it makes use of biometrical quantities, notably *means* which measure average grades of expression, *variances* which measure variation in expression within generations and families, and *covariances* which measure relations between generations and families. Using these quantities, the total variation in the character is separated into the heritable and the non-heritable, the fraction which the heritable variation constitutes of the

whole providing a measure of so-called heritability of the character. This heritable portion must be further subdivided into a fraction depending on simple additive effects of the genes, a fraction depending on dominance, and a fraction depending on the interaction of the genes, that is on their abilities to enhance or reduce each other's effects disproportionately. These fractions are of diverse genetical causation and they have different consequences. Indeed the portion depending on interaction may usefully be subdivided further for the same reason. Finally any contribution to the variation of still other factors, such as direct nutritive effects of mother on offspring or the special interaction of genetical constitution and environment, must be recognised and measured as these too have different consequences in heredity. The mathematics involved are often complex and the experiments elaborate in design. Much remains still to be done, but valuable progress has been made in the past fifteen years or so.

THE PLANT BREEDER'S PROBLEM

The significance of these developments for the plant breeder springs from the simple but central fact that by far the greater portion of the variation with which he is concerned is of this continuous kind. Yield, quality, ability to withstand adverse conditions, much disease resistance too—all are characters which will show continuous variation in his breeding material. His choice of parents for breeding his improved strains and varieties; his method of procedure in selecting, reassociating and fixing the characters at which he is aiming; his building of a foundation stock for the multiplication and distribution of seed; his decision to adopt special breeding methods as for example by using radiation to induce new variation; all must rest on his assessment of the genetical situation which faces him, and with continuous variation efficient assessment can seldom avoid drawing on the resources which biometrical genetics has to offer.

Prospective Value of a Cross

In seeking to provide improved varieties plant breeders, unlike animal breeders, nowadays depend very little on selection from an already available population: generally they initiate the breeding programme by deliberately hybridising existing forms. Usually a number of possible parents are available for use and the choice amongst them will in no small measure determine the success of the operation. Where the aim is to achieve a new combination of desirable characters, such as the high yield of one type with the high quality of another, the choice of parents will be determined at least in part by these requirements. In other cases the aim is to achieve a higher expression of a character by introducing from the two parents different genes promoting the character and so producing a combination of genes superior to the ancestral types. The prospective value of a cross will then depend on the existence in the parents not merely of different genes promoting the expression of the character but of genes which can readily be brought together in a single derived type and which will combine well in producing their effects. In other words, the genes must be capable of ready recombination and should preferably interact so as to enhance one another's effects when they are brought together—or at least should not unduly diminish them.

Early information on the linkage relation and, perhaps even more important, the interactions of those genes in which the parents of a cross differ, is essential if the breeder is to use his time and facilities efficiently. In principle, means are already available for assessing at the second or third generation after crossing the magnitude of genetic differences between parent lines, of detecting and assessing the importance of any linkage that the genes may show, and of provisionally predicting the limits to which the character may be modified by selection. In practice, while the genetical theory is available, the necessary biometrical analysis has encountered difficulties of a statistical kind, which must be overcome if success is to be generally achievable. Methods of analysis are under investigation² and the use of electronic computers may help in overcoming the difficulties. A panel of prospective parent lines can, however, already be tested for desirable interactions among their genes at only the first generation (F_1) after crossing. The technique is that of diallel analysis^{3, 4}.

In a set of diallel crosses every parent is crossed with every other, the parents and their F_1 's then being grown together in a single experiment. Where the parents are true breeding, as is the case, for example, in all our important cereals, appropriate biometrical analyses on the combined observations of the parental and hybrid families will show whether genetical differences exist among them, whether dominance is important, how the parents differ the relative preponderance of dominance shown by the genes each carries, and most important whether the genes from the various parents interact in producing their effects. Furthermore enhancing interactions can generally be distinguished from those which diminish the gene effects. The crosses of parents whose genes show desirable relations can then be chosen for the further breeding operations aimed at fixing the new and valuable genic combinations which diallel analysis has shown to be possible. The process can of course be repeated at later stages among the lines derived by breeding.

As a result of visits by breeders from overseas, this technique, has so to speak, been exported, and its practical application is undergoing testing and development both in this country⁵ and abroad. A test made in the U.S.A. on existing results has already proved encouraging⁶. Meanwhile theoretical investigation of diallel analysis continues, especially in relation to certain ambiguities which can appear in its interpretation and in its extension to the more complex cases of diallels made among parents which are not true breeding⁷.

Selection

When a cross has been made, selection must be practised among its descendants in order to isolate and fix lines showing the most desirable manifestation of the character or combination of characters. This raises its own questions of how the selection should be applied and how the material should be manipulated genetically to give selection its greatest chance of success. The answers to these questions vary with both the species and the characters concerned.

Where the value of an individual can be assessed confidently by the measurement of the characters it itself displays, little difficulty arises in its selection or rejection from the material from which later generations will

be bred. But where, as is frequently the case, non-heritable variation is so great that observation of a single individual tells one but little of its breeding value, that individual must be judged by its progeny rather than by its own performance. To test an individual's progeny, however, requires that a number of its offspring be grown, and the larger the progeny required the fewer the individuals that can be tested. If the progeny is kept small obviously more individuals can be tested out, but the value of each parent is then less adequately assessed. There is thus a question of balance in the allocation of available facilities in a breeding programme, a need for arriving at an optimal division between size of progeny and number of parents tested. This optimum will depend in its turn on the heritability of the character in question. With higher heritability, test progenies need not be large and progeny testing may indeed be avoided altogether; but with low heritabilities larger progenies may be required. The genetical analysis and calculations necessary for the efficient design of such programmes are more familiar in animal than in plant breeding⁸, but the principles involved are the same at least where the plant species under improvement is a natural cross-pollinator, as are for example sugar beet and the brassicas.

With self-pollinating plants, like the cereals, the problem may appear in a somewhat different guise. Selection in the early generations derived from a cross may not be desirable, or it may be ineffective because the plants are still partly hybrid with dominance obscuring the effects to be expected of the gene combination when these have reached the true-breeding condition to which the natural self-pollination will ultimately lead. The descendants of a cross will thus commonly bulk up so rapidly that when assessment of the by now virtually true-breeding families comes to be undertaken in later generations, available facilities may prove insufficient to grow from all of them the number of plants which fully adequate testing would demand. The choice is then between a less exact assessment of a large number of families and a more exact assessment of a smaller number. Again, given a quantitative understanding of the genetical situation, a design can be worked out to strike a balance between these conflicting requirements. At times it even proves advantageous to reject at random a sizeable fraction of the families available in order that the worth of the remainder can be more adequately assessed and selection practised to best effect⁹.

Within the limits set by the requisite testing procedure, the speed and ultimate limits of progress under selection will be determined by the genetical manipulation of the plants, and in particular by the way they are mated together in each generation to produce the next. This in its turn will depend on the relative ease with which self- and cross-pollination can be brought about. With cereals for example, artificial cross-pollination is so laborious that after the initial cross most of the breeding must be by natural self-pollination. This, however, will necessarily limit the opportunities for recombination among the genes brought in from the two parents—the recombination upon which depends the ultimate progress under selection whether for enhanced expression of a single character or the achievement of a new combination of several desirable features. In species where crossing is not so difficult more varied mating systems are

possible and once again a balance of advantage must be considered in choosing among them. The mating of good but more distantly related individuals among the descendants of the initial cross could in the long run lead to greater progress than selfing or the crossing of more closely related individuals because of the greater opportunity it offers for recombination, but fixation of the character at an improved level would then necessarily be delayed. There is a little evidence that such assortative mating does indeed offer a balance of advantages as compared with self-pollination¹⁰, but further study, both theoretical and experimental, will be needed before the plant breeder's questions can be answered with the confidence and precision that is their due.

Building Strains

With naturally self-pollinating species, the building up of a variety for multiplication and distribution poses no great problem of principle. Once a true-breeding individual of the desired type has been obtained its progeny, produced by the self-pollination, will share its character and they may thus be allowed to multiply by their natural process.

With natural cross-breeders, however, the situation is different. The individuals of the species are not naturally true-breeding, and if self-pollination is practised or even the mating of over-close relatives such as would give rise to true-breeding individuals, inbreeding depression will result. The strain must therefore be built up by pollination among a number of different individuals. At the same time its variation must be held within acceptable limits in respect of the practically important characters, and if too many individuals go into the foundation stock variation in the derived population may become over-wide. The problem arises, therefore, of how many foundation individuals to use: too few will lead to inbreeding depression and too many to undesirably wide variation. The optimal number of individuals must be expected to vary with their ability to combine well with one another in respect of their genetical constitutions. This clearly is a question requiring the approach and methods of biometrical genetics for its investigation. The first experimental work was begun a number of years ago¹¹, and it has been taken up more recently at other plant breeding stations. It seems likely that the optimal number of individuals in the foundation stock will be lower than has been commonly thought necessary in the past.

The nature of hybrid vigour

The practice, which has been so successful in maize, of using for commercial production seed obtained by deliberate crossing has been extended to other crops. The value of such hybrid seed is that it enables full advantage to be taken of the valuable hybrid vigour which can be obtained in the progeny of crosses between suitably chosen parent stocks. This kind of plant breeding meets with its own difficulties among the chief of which are the securing of regular crossing between the chosen lines, the maintenance of these parent lines which are preferably inbred and therefore commonly weak, and the discovery of parent lines which combine well in crosses. The discovery of lines which combine well on crossing and the strengthening of the parent lines without loss of combining ability would be greatly facilitated by an understanding of the genetical nature

of hybrid vigour, without which indeed these breeding operations can never be carried on in a fully efficient manner.

Several hypotheses have been advanced from time to time as to the genetical causation of hybrid vigour, the two most important of which are, first, that it is due to a kind of exaggerated dominance of the genes—over-dominance as it is called—such that an individual hybrid for a given pair of alternative genes (e.g. Aa) is more vigorous, taller, better-yielding or whatever it may be (depending on the character in question) than those true breeding for these genes (i.e. AA or aa); and, second, that it depends on interactions between non-alternative genes (e.g. A and B) in producing their effects. A decision between these views is important because the breeding techniques to which they lead are necessarily different. Analysis of diallel crosses in a number of different species of plants, some like maize and cotton of commercial importance and others not, has given firm indications of interactions among the genes, but no clear evidence of over-dominance¹². The nature of the interaction must, however, be investigated in greater detail, since on this will depend the development of techniques for the maximum utilization of these interactions and for the building-up of combinations of genes which will extend them still further.

CONCLUSION

As the study of continuous variation, biometrical genetics is not confined in its application to plant and animal breeding: it is of interest also, for example, to the study of adaptation and evolution, and indeed plant and animal improvement may be regarded as a form of artificially produced and controlled evolution. Yet the relation to such breeding work is a special one. Not only is the development of biometrical genetics required for the help it can give to the breeder, but its rise during the last decade or so has been due in no small measure to the stimulus provided by the scientific problems that practical breeding has thrown up. The traffic is thus in both directions. Not only should the breeder be able to look to biometrical genetics for a basis on which to build the wider and more efficient breeding techniques he must always be seeking but the geneticist for his part can gain nothing but advantage from seeing his science put to the test of practice and from the stimulus of the problem which practice is continually revealing. With the encouragement that recent applications have given to the breeder to undertake the measurement and biometrical analysis of the variation with which he is dealing, there is every prospect that this mutually valuable link will continue to grow closer.

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THE ASSESSMENT OF CROP LOSSES CAUSED BY DISEASES AND PESTS

(The Plant Pathology Laboratory of the Ministry of Agriculture, Fisheries and Food has for the past ten years devoted special attention to the assessment of losses caused by diseases and pests of crops. As a knowledge of these losses is basic to the proper planning of research on the organisms that cause them, the Council had pleasure in inviting the Plant Pathology Laboratory to contribute the following article.)

Since 1917, the collected reports on diseases and insect pests of crops in England and Wales have provided very full information on the diseases and pests present in the country, their identity, the nature of the damage they cause, their control, and to some extent their distribution. But the actual magnitude of the losses to which they give rise is difficult to determine, and until recent years has remained almost entirely a matter for speculation¹.

In 1950, a special section was started at the Ministry of Agriculture, Fisheries and Food's Plant Pathology Laboratory at Harpenden for the express purpose of developing methods of measuring diseases and pests on crops, and of applying these methods in country-wide surveys. The aim was to determine their incidence in relation to seasonal and regional conditions, and ultimately to discover the connection between the degree of attack at particular stages of growth of the host plants and the loss of yield at harvest².

The unbiased quantitative information obtained in this disease measurement work serves for the guidance of national policy in the application of control measures, and now provides the basis for much advisory work. It reveals when and in what circumstances spray treatments are needed, and when and where their use is wasteful or even detrimental. It brings to light possible variations of cultural methods that may be used for pest or disease escape; and it indicates directions in which plant breeding for disease resistance can most profitably be extended.

In this article the work on plant diseases is described in the first part and that on insect and other pests in the second part.

PLANT DISEASE ASSESSMENT

A Disease Assessment Committee of the N.A.A.S. Conference of Plant Pathologists works with the Plant Pathology Laboratory on the evolution of methods and puts forward survey schemes, which, when adopted, become projects of the Conference. They are carried out by the N.A.A.S., with

the collaboration of research stations, the National Institute of Agricultural Botany, and other bodies. Most of the work of collating the survey results is done in the disease assessment section of the Plant Pathology Laboratory, and the journal *Plant Pathology*, started in 1952 and edited at the Laboratory, is the main vehicle for the publication of results.

Methods of measurement and survey procedures have to be worked out individually for each plant disease. There are no portmanteaux methods. Representative plants at successive stages of growth and of attack by the disease are first collected, dissected and measured in detail. Research methods of assessment are explored, and with their help a simple field key is gradually evolved, based on the peculiarities of the particular host plant, and on observed phenomena in the field. The field key is such that it can be used quickly and easily by any field officer. There is usually a pilot survey with the key in a restricted area of the country; and this is followed by a main survey lasting at least three seasons.

Potato Blight

Disease measurement methods have been worked out and applied more fully for potato blight in England and Wales than for any other disease in any part of the world—with the possible exception of Black Stem Rust of wheat in North America. The date of outbreak and subsequent progress of the disease on the potato foliage has been systematically recorded year after year on maincrops throughout the country. The frequency with which blight attacks of various precisely defined degrees of severity occur in the different regions has been determined on a long-term basis; the gains and losses from protective spraying and haulm destruction have been realistically computed; and the national losses from the disease over a ten-year period have been analysed³.

The information from the survey work revealing the times of blight outbreaks in the various years has made it possible to develop, check and counter-check a blight forecasting system, which now gives 10 to 14 days' warning each year of outbreaks in all the principal potato growing areas^{4, 5}. These forecasts help growers to time their spraying to the best advantage, where spraying is required, and to economise and avoid incidental loss of crop by spray and machinery damage, where spraying is unnecessary.

Much work has been done in collaboration with the Potato Marketing Board in surveying losses from blight in tubers, which has supported the findings of country-wide field trials⁶ in showing the relatively slight effect of haulm destruction on the reduction of these losses, and pointed the economic need for more work on breeding tuber-resistant varieties.

Over the years 1955–57 the University of Wisconsin provided financial assistance which enabled the Plant Pathology Laboratory to review potato blight epidemics throughout the world by the methods and in the light of experience gained in England and Wales. This substantial work will be published in book form by the U.S.D.A. Government Printing Office in Washington⁷.

Potato Scab

Although Common Scab is one of the most prevalent diseases affecting the marketable quality of potatoes, there was, until the disease-assessment

work began, no information on the extent to which it really affects our crops. A diagrammatic key was worked out and tested for this disease, and since 1952 this key has been employed for the assessment of scab on some 2,500 potato crops in Great Britain each year⁸. These surveys, carried out by the Potato Division of the Ministry of Food and later by the Potato Marketing Board, in collaboration with the Plant Pathology Laboratory, have shown that in dry seasons about 4 per cent of the tubers in the total national potato crop are objectionably scabbed (over 25 per cent of their surface area affected), while in wet seasons the proportion is only about 2 per cent or less. In this case the disease is *not* of most consequence where most potatoes are grown. In the Fens, and elsewhere on the best potato land the incidence is relatively low; it is in the "marginal" potato lands, and in the Keuper marl areas that the incidence is highest. The work has provided much practical information of importance to potato breeders.

Cereal Mildew

For generations opinion has been divided as to the real significance of mildew on cereals, some contending that its effect on yield is trivial, others that it causes much loss. The task of devising a reliable field key for cereal mildew was very difficult for the reason that the normal senescence of cereal leaves is all too easily confused with the premature yellowing and drying up of the leaves caused by the disease. Before even starting on the assessment of mildew it was therefore necessary to make a very full and careful study of the normal course of senescence. Representative plants of healthy wheat, rye, barley and oats, of several varieties, were collected in various parts of the country, drawn to scale and analysed for leaf area, at intervals of a week to a fortnight, from the earliest seedling stage until harvest over three entire seasons. On the basis of this detailed work an illustrated key to cereal growth stages was obtained⁹. This key, in a sense a mere by-product of the work on mildew, has proved to be extremely useful, not only to plant pathologists, but also to plant breeders, agronomists and entomologists, at home and abroad, wherever the stages of growth of cereal crops have to be recognised and defined. The key was of particular service in defining stages at which growth-regulator weed killers could safely be applied.

Once the standard key to growth stages was available and in use, it became possible, by detailed observations on many crops, to draw up a field key for mildew, defining the percentage of the functional leaf area affected by the disease at any stage of growth. The next step was to explore the relationship between the amount of mildew present in a crop at given stages of growth and the eventual yield of grain. Last¹⁰, at Rothamsted, had shown that a crop could be kept virtually free from mildew by periodic spraying with lime sulphur. Therefore, in joint work now in progress with the National Institute of Agricultural Botany, the yields from plots treated in this way are being compared with those from untreated plots of the same cereal varieties, in which mildew develops to varying degree according to locality and season. The trials are continuing on three cereals at 12 centres for three years. The indication from the work so far is that mildew attacks of commonly occurring severity do in fact cause a significant reduction in yield, particularly in oats and barley. The reduction may be of the

order of 5 per cent, so that research on the breeding of mildew resistant varieties has ample economic justification.

Loose smut of cereals is a disease that it is comparatively easy to assess in the field ; it is necessary merely to count the number of smutted ears in a sufficient number of sample areas. Former assessments were based on a long-assumed general average of 1 million ears per acre for cereal crops. A survey was made to check this figure ; it was found that nowadays, with present varieties and cultural practices, the general figure is more nearly $1\frac{1}{2}$ million ears per acre in wheat and oats and 2 million in barley¹¹.

Choke in Cocksfoot Grass

A few years ago there was much concern about the occurrence of Choke, caused by the Reed Mace fungus, *Epichloe typhina*, in seed crops of cocksfoot. The disease "chokes" the infected flower-bearing tillers so that they do not arise and the grass is barren. In work carried out in collaboration with the Welsh Plant Breeding Station the disease was assessed in almost every certified seed crop of the grass over a period of three years¹². As a result of this work it was found that the mean loss from the disease was about 3 per cent of the total seed crop ; but that the loss varied very greatly according to the age of the stand. It was much greater in old stands that had been down for 5 to 7 years than in those more recently planted. Many of the older stands were found to be unproductive, owing to weed growth and other causes, so that the elimination of all but the best of them was shown to be an economic and important control measure for this disease.

Clover Rot

"Clover sickness" has been a trouble on our farms for generations. It is now known to be caused in part by a fungus disease, Clover Rot (*Sclerotinia trifoliorum*) and in part by eelworm. In the years 1953-55, after much preliminary work on methods and the testing of questionnaires, a survey was made in fields of red clover, or leys containing red clover, over the whole of England and Wales¹³. In 1953 and 1954 when the incidence of the disease was about normal, it was found to be very rare in Wales, but present in about 70 per cent of the 500 fields surveyed in England. The loss of red clover stand at the end of winter was between 6 to 24 per cent in 10 per cent of the fields, and over 24 per cent in a further 10 per cent of them. Where the loss of stand was not more than about 5 per cent the amount of clover in the eventual crop was generally little affected. Higher losses of stand caused variable but often substantial loss of clover, with grasses in the leys tending to fill the gaps. The disease was found to be most frequent and severe in parts of England where four or five course rotation is practised and one-year leys containing red clover are the rule. In the course of this work eelworm was recorded in about 20 per cent of the fields, and moderate or severe loss of stand from this cause was found in about 7 per cent of the fields each year.

Apple scab is one of the fungus diseases of major importance in England and as the apple crop is a valuable one, large sums are spent each year by growers on scab control. In the first volume of "Plant Pathology" keys were published for the rapid assessment of the disease on both leaves and fruit^{14 15}. These keys have been widely used and are now being employed

in special surveys of spray practice to assess the level of scab control achieved with various spraying programmes. Following the work of Storey, Hirst, Ward and others, who found that "curative" spraying programmes based on infection periods rather than "protective" spraying based on bud stages gave greatly improved control of scab in the Wisbech area^{16, 17}, much very detailed disease-assessment work has been done on this disease. A study has been made of the distribution of scab lesions on the foliage in relation to the exposure of new and susceptible growth at times when weather conditions are conducive to infection. The practical possibilities of recognising such conditions by the Mills rules and by other meteorological criteria are being explored, and scab assessment is playing an important part in very cautious advisory work affecting changes in spray practice.

Since 1950, *Verticillium wilt of lucerne* has become an advisory problem in certain parts of England. In 1958 a full-scale national survey was started to ascertain the actual distribution of the disease in the country, the precise extent to which it is affecting the crops in the several regions, and the influence of a number of cultural and environmental factors on its incidence and spread. The experience gained from the survey of clover rot proved to be of great help in planning the work on this disease. In 1958, the first year of the survey, about 4,000 acres of lucerne were examined in the country as a whole, and the disease was found to be present at 84 of the 123 survey centres. In general the incidence of wilt was found to be highest in the regions and on the farms where most lucerne is grown; and there was found to be a progressive increase in severity of the disease with the age of the lucerne stand up to four years but not beyond that age. A very important part of this survey is the investigation of routes of spread. The survey will continue for three years.

Other Diseases

Tentative keys have been worked out, and preliminary or limited regional surveys have been made, for a number of other diseases, including the rusts of cereals, apple mildew and brown rot, rose mildew, tulip fire, tomato leaf mould¹⁸, chocolate spot of beans, club root of brassicae¹⁹, broccoli mosaic, yellow mosaic in broccoli²⁰, black currant leaf spot, and chrysanthemum diseases. A substantial body of information on the technology of disease assessment has already been built up in the volumes of "Plant Pathology".

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PEST ASSESSMENT

In his book "Farm Pests", published in 1859, Curtis gave a few estimates of losses caused by insects—mostly as quotations from letters received from practical farmers. His purpose was economic: publication could stimulate interest in ways of avoiding pest damage, and perhaps encourage investment in research to this end.

These aims remain to-day. Prevention is always better than cure, and the main justification for pest assessment lies in the possibility of discovering what factors cause sudden increases in insect numbers in the field, and how to manipulate them to the farmers' permanent advantage. Where conditions are such that manipulation is out of the question, forecasting systems can do much to ensure that pesticides are applied only at the right times and in the right places.

In loss assessment, cultural manipulation, and forecasting, the basic problems are the same: progress cannot be made until pest density and activity can be measured in the field in relation to the growth of the crops which are attacked. The wartime wireworm survey¹—a co-operative venture in which all the advisory entomologists as well as workers at several research departments co-operated—emphasised the value of a co-ordinated approach to quantitative assessment. The results were the first to give a substantially objective picture of a pest over the country as a whole, and by the end of the war Advisers were no longer satisfied with subjective opinions on pest numbers and damage. With the return of peace the Conference of Advisory Entomologists set up a Sub-Committee to co-ordinate and develop objective pest assessment work, and since 1946 this Committee has actively attacked the problems put to it by the parent Conference.

One fact soon became clear to those engaged in developing this work. Most pests are quite easy to count; but a single record of the number of insects on a plant, or an estimate of the number per foot of crop row or per acre, can be remarkably uninformative unless a great deal is also known about the precise conditions under which the crop is growing. Difficulties in interpreting survey results—even though they were obtained in statistically satisfactory ways—led the Advisers to review their programme in 1950. In this year an officer at the Plant Pathology Laboratory was appointed permanent Secretary of the Pest Assessment Committee to ensure continuity in the development of the work.

Since insect counts alone have little meaning a new programme was developed to relate pest activity and density directly to crop growth by means of field trials set up throughout the country and adequately replicated in space and time. The experimental results were to be used in conjunction with data from surveys in commercial crops to arrive at an overall picture of what had happened, or was likely to happen, within any one of the N.A.A.S. Regions, or over the country as a whole. This dual approach has worked well, and it is appropriate to summarise some of the results obtained over the past decade to illustrate the problems which arise and the way solutions, or partial solutions, to them are found. But first one point must be emphasised. Crop work is complex, and doubly so where an active insect is superimposed upon the variables inherent in soil, seed, and weather. Much work must be done if progress is to be made with any pest loss, or pest forecasting, problem, and it cannot be too strongly stated that no useful results would have been obtained in the last ten years but for first-rate co-operation between the advisory entomologists, between them and their non-specialist colleagues in the N.A.A.S. and the Potato Marketing Board, and between the members of the Pest Assessment Committee and many research workers.

Cabbage aphid was chosen for detailed study in 1950 because a good deal was already known about its distribution and habits. Four years of co-operative experimental work enabled fair estimates to be made of national losses in Brussels sprouts, the average being 7,500 equivalent acres per annum, or about 14 per cent of the annual production². It was also shown that normal commercial sprays applied in August or September were unlikely to recover more than half of the loss in yield, and an attempt was made to define the low June and July aphid density levels which, though hardly noticeable to the grower, would more often than not repay treatment. A major difficulty is the great reproductive potential of aphids in favourable conditions, which means that pest forecasting is not possible in the absence of long-range weather forecasts.

Concurrently with the cabbage aphid work a national survey of *rabbit damage* was done during the winter seasons 1951–52 and 1953–54 to assess losses due to grazing of winter corn. The experimental details were based on rabbit biology studies at the Ministry's Infestation Control Division laboratory at Tolworth. Over 300 trials were done on commercial cereal crops, selected on a scheme devised by the Rothamsted Statistics Department. Results over the two seasons were consistent, and indicated that winter cereal yields throughout England and Wales were reduced by about 1½ cwt.

of grain per acre through rabbit grazing^{3, 4}. Thirty per cent of all winter cereal crops were moderately or severely grazed, with yield reductions of up to 20 per cent. It would be interesting to repeat this work now that myxomatosis has so greatly reduced the rabbit population.

Work on *frit fly* was started in 1953 after a preliminary season of work by Plant Pathology Laboratory in collaboration with workers at the Imperial College Field Station. By 1957 results from 76 field trials were available, and it was possible to interpret extensive survey results which had accumulated over a 12-year period⁵. It was shown that losses due to attack on oats amounted to over 250,000 equivalent acres each year, and that grain damage alone accounted for the greater part of this loss. Work is now in hand at Rothamsted, at the Ministry of Agriculture's Plant Pathology Laboratory, at King's College, Newcastle, and at several N.A.A.S. Regional Centres, aimed at forecasting the likely intensity of spring damage to young shoots and summer damage to grain with a view to rationalising possible control measures. Concurrently it has become clear that frit can do considerable damage to young ryegrass and fescue leys, and to some winter cereals drilled after ploughing out leys containing these grasses. These problems are being looked at by N.A.A.S. entomologists and by the Grassland Research Institute.

Co-operative work on *clover weevil* was begun in 1955, partly to assess the need for the widespread routine spraying which was then being done in some parts of the country, and partly to assess the effect of such sprays on seed set and on the insect fauna of clover seed crops in general. The latter work was done in close liaison with the N.I.A.B. Seed Production Branch and the Bee Department at Rothamsted. A number of difficulties were encountered in this work and by the end of the 1956 season it was decided to shelve the project. The two years' work did, however, indicate that control of weevil by spraying is not always economic. DDT treatment is of doubtful value on double-cut varieties where the first flush of pests is carted off the field in hay bales, while the main flush often appears before the mown crop has had time to produce many flower heads. The situation is complicated by ordinary harvesting problems. In an average year perhaps only half the seed set in a clover crop gets into the grower's barn because of an extended maturation period coupled with the inevitable weather difficulties. In these circumstances weevil losses are usually trivial in double-cut crops. Single-cut varieties pose problems of their own because early weevil migrants are not removed with a hay cut and because of the difficulty of getting tractor-drawn sprayers through the crop at the right time⁶.

When the clover work was shelved the entomologists turned their attention to peas. Their aims were to estimate the present status of *pea root eelworm*, *pea weevil*, and *pea moth*.

Eelworms are difficult pests to assess but a survey of the main pea growing areas over two seasons suggests that about 4 per cent of pea fields are currently infested. However, an intensive survey done by the N.A.A.S. entomologists in the Eastern Counties indicates that two or three times this number may be infested in some districts in which processing factories are situated.

Although the investigations on *pea weevil* are still in hand, it appears from the data already collected that this pest is generally of little importance,

and that provided the fertility of a field is good the pea plant can lose a high proportion of its root nodules without any detectable effect on growth or yield.

Work on *pea moth* has been done concurrently with that on weevil. It is clear that vining is itself a form of moth control; where haulm is carted off the farm for treatment it has meant the virtual disappearance of pea stacks in some areas where they were once a common sight. The absence of such sources of infestation, in and under which moth grubs can complete their overwintering development in large numbers, is likely to have important long-term effects on moth density. In the meanwhile, it has become obvious that a good deal of spraying for the control of pea moth is done as a routine, sometimes when not necessary, and at other times too early or too late to have the right effect. Intensive work on the feasibility of forecasting outbreaks has therefore been started, and N.A.A.S. workers in the Eastern and South Eastern Regions are collaborating with the Plant Pathology Laboratory and the National Vegetable Research Station in developing forecasting and spray warning systems.

The field experimental work already discussed refers to pests of general importance, about which a certain amount was known before the investigations were started. Other work has been done on species important mainly in particular areas or on specialised crops. The N.A.A.S. Eastern Region entomologists, for instance, have done a great deal of work on the losses due to, and means of forecasting, *wheat bulb fly*⁷, and for the past three seasons have collaborated with other N.A.A.S. entomologists, and with workers at Rothamsted, on chemical control trials. Some excellent work on losses in sugar beet due to *virus yellows*^{8,9} has been done by workers at Dunholme Field Station in collaboration with British Sugar Corporation field staff. This has developed into a forecasting service, and spray warnings are now issued when necessary throughout the beet growing areas¹⁰. Further work on beet has taken the form of co-operative trials by Dunholme workers and N.A.A.S. entomologists in Wales and the East Midlands on the importance of *mangold fly* in beet and mangolds. The results show that this fly, spectacular though its effects may seem, is seldom worth the cost of chemical control, though this is a situation which might change rapidly if precision seeders were to become widely used.

Another interesting piece of specialised crop work has been done on *cabbage root fly* at the National Vegetable Research Station. Some years ago it was thought that the extent of damage to early cauliflowers by this fly depended on the rainfall in May and June, when the crop is subject to attack. In wet years damage is usually less, and this was attributed to there being ample water-absorbing roots left undamaged, so that water stress did not develop and the plants were able to grow away from the attack¹¹. However, recent work at Wellesbourne has shown that fewer eggs are laid in wet seasons; also, that heavy showers of rain in otherwise dry seasons cause many eggs to be covered with mud splashes and soil particles so that the partly hidden eggs are not readily found by the small beetle which normally eats a large proportion of them.

Other investigations worthy of mention include work on *timothy fly* in relation to seed yields¹². This fly has recently been critically investigated

in Sweden¹³, where the damage it causes appears to be more severe than in England. *Leatherjackets* in grassland have been surveyed by Regional entomologists for many years, and local warnings are given in the press and over the radio when density is high enough to warrant baiting. Detailed plot work on yield losses in cereals after ploughing out infested grassland is in hand in the Northern Region. Lastly, a severe outbreak of *wheat blossom midges* did very considerable damage in Eire in 1951 and in Germany in 1953 and 1954^{14, 15}, and in 1954 work was started at the Plant Pathology Laboratory on these pests. Fortunately, the unknown combination of circumstances which triggered off the devastating attacks in Eire and on the Continent did not occur in this country, and after three seasons of field trials in which too few midges were present to have a detectable effect on yields the work was terminated¹⁶.

It has already been said that eelworms are difficult pests to assess. Both quantitative and qualitative methods were used to estimate the incidence of pea root eelworm; with cereal root eelworm quantitative methods alone were used¹⁷, while the *tulip eelworm* survey, done in 1955¹⁸ involved visual inspection only. This eelworm, it was shown, infested about 12 per cent of the tulip stocks in the Holland Division of Lincolnshire, about 6 per cent in the rest of the Eastern Counties, and only 2 per cent in the rest of the country.

The pests discussed so far are mostly important because they, or the virus diseases they transmit, reduce gross yield. Many species reduce quality rather than quantity, and for the past five years the Plant Pathology Laboratory has collaborated with the Potato Marketing Board crop Inspectors in annual surveys of damage to the ware crop caused by *slugs* and *wireworms*¹⁹. Estimates are made in the field just before lifting, and about 2,500 crops are examined each year. In the last year for which records are available (1958) wireworms damaged 274,000 tons of ware potatoes. However, most of the damage was trivial, amounting to a few hundredweights of superficially damaged tubers in a gross yield of about 8 tons per acre, and much of it was riddled out before crops were bagged for market. The final estimate of net loss due to wireworm was only 47,000 tons, or 1.4 per cent of the total ware production. Slug damage was worse in 1958 than for some years, presumably due to the abnormally wet season; gross damage amounted to 520,000 tons, the net figure, after riddling crops with only slight damage, being 13,000 tons. These losses are not additive, because a tuber damaged by wireworm, and therefore unsaleable, is not down-graded further because it is also damaged by slugs. About 5 per cent of tubers tend to be damaged by both pests, and the final corrected estimate of ware damaged by both pests in 1958 was 58,000 tons.

Advantage has been taken of the Potato Marketing Board check weighing scheme to get information on *insecticide usage* by potato growers. It appears that at present about 20 per cent of the ware crops in England and Wales receive soil insecticides for wireworm control. Such studies are complementary to the work on pest assessment. There is little information on the extent to which growers use modern insecticides, and what there is suggests that there is a good deal of routine use of chemicals, presumably as a form of crop insurance. Thus, it is difficult to understand why so many growers

use soil insecticides on their potatoes when, even before the advent of these chemicals, wireworm damage apparently did not occur on more than about 10 per cent of the crops. It was calculated that, in 1956, probably only one field out of every five which received soil insecticide had a large enough wireworm population to make use of the chemical worthwhile.

Further information on the use of insecticides, in this instance relating to cereals, peas, swedes, and kale, was obtained from the Survey of Fertiliser Practice in 12 districts in 1954²⁰. In East Sussex, for example, 70 per cent of the kale crops were treated for flea beetle, whereas only about 6 per cent were so treated in wetter areas of the country. Two recent surveys done by N.A.A.S. District Officers related to spray usage in 1954 on Brussels sprouts and in 1957 on strawberries. Apparently in a normal year about a third of the sprout fields receive aphid sprays, while in 1957 strawberry growers spent about £60,000 on sprays and their application; in the absence of careful field work on pest incidence in relation to yield it is not possible to say how necessary, or how effective, this expenditure was.

It is evident from this review that the entomologists' approach to pest density problems is producing useful results, both in establishing limits in the incidence of various species beyond which the cost of control measures should be fully justified and in providing a basis for warnings as to when treatment is deemed necessary. A good deal is already known about the population densities and times at which control of some pests is most worthwhile, but regional or national warnings can be given only when sufficient information about infestation is available from samples of crops in the main growing areas. Extension of the system of area warnings is thus limited less by entomological knowledge than by the manpower available for surveys.

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CONTROLLED ENVIRONMENT FACILITIES FOR PLANT RESEARCH

The plant environment is a system of great complexity, comprising a number of factors such as the amount and daily duration of light, the temperature and humidity of the air, and the availability of water in the soil, all of which affect the growth of plants and the yields of agricultural crops. It is common for crop yields to vary by 50 per cent from one year to the next on the same soil and under the same management, due to differences in weather in successive seasons. These variations are often ascribed to obvious variations in the weather such as “a cold spring” or “a dry summer”, but this is an over-simplification. The plant responds simultaneously to changes in each of the environmental factors and the ultimate level of yield is the result of the effects of all the environmental conditions experienced throughout life.

Although the effects of weather on plants are of such great agronomic importance, our knowledge of them is still fragmentary, due to the great practical difficulties of studying the precise effects of all the constantly-changing environmental factors. Each factor can be measured separately but it is difficult to assess the influence of individual components of a weather system in which each factor can vary rapidly, widely, unpredictably and independently of the others. Moreover, the single criterion of yield, although the agricultural end-point in crop production, is a poor means of assessing the effects of weather over a whole growing season, since the influence of adverse growing conditions at one season may often be masked by exceptionally favourable weather at another.

Important advances, however, are now being made in this field of study because of recent technical developments of three separate kinds, namely (a) the introduction of more precise ways of measuring the factors of the plant micro-climate, (b) the perfecting of techniques for assessing the behaviour of plants over short periods of time, and (c) the development of equipment for the control of plant environments on an experimental scale. All three techniques are essential to the study of the effects of weather on plants and all are now being put to use. Interest in the measurement of the plant micro-climate is increasing rapidly and much valuable work is being done (e.g., at Rothamsted⁸). Techniques for the analysis of growth and the assessment of plant efficiency were worked out many years ago¹

although their value in agronomic research is only now being appreciated². Finally the development of "controlled environments", in which plant behaviour can be studied in relation to various factors of the environment, is now providing a new and powerful research tool that is likely to have far-reaching effects on agronomic research.

TYPES OF CONTROLLED ENVIRONMENTS

To grow normal healthy plants to maturity under strictly definable conditions, it is necessary to control temperature within close limits and provide light of relatively high intensity and known spectral composition. Advances in the technology of air conditioning have led to the production of relatively cheap equipment for cooling and heating air, and for the control of air humidity. It was not, however, until the fortunate, though fortuitous, introduction of novel ranges of electric lamps, with new characteristics, that it was possible to grow healthy green plants under artificial light and thus, for the first time, to become independent of the random fluctuations of natural light. This development, more than any other, has made it possible to study the behaviour of normal plants growing under controlled conditions. It is now possible for a wide range of species, including crop plants, to be grown to maturity in opaque rooms where the main factors of the environment can all be controlled within reasonably close limits.

A number of earlier workers became interested in controlled environments for experimental work, but the Earhart Plant Research Laboratory at Pasadena, California, opened in 1949, first showed the advantages of providing a wide range of different controlled environments within a single installation¹⁰. Interest in the use of controlled environments for experimental work has grown very rapidly in the few years since the opening of the Earhart Laboratory (which subsequently came to be known as the "Phytotron"). Large installations have been opened, or are being built, in Australia, France, Holland, New Zealand and elsewhere, but developments in Britain have taken a rather different direction, being based on the construction of less elaborate installations at a number of research centres rather than at one large central institution. A recent survey⁴ showed that some 70 university departments and research institutes in Britain now have facilities for work in controlled environments. Although these are all limited, the over-riding advantages of dispersing such facilities are that they thus become available to a much larger number of research workers, and for a wider range of purposes, than if they were concentrated at a single centre.

The main forms of equipment at present used for providing controlled plant environments are as follows:—

Growth cabinets, which are small structures in which green plants can be grown, but which are not large enough to admit the operator, who gains access to the plants from outside. Cabinets may be opaque and provided with artificial light, or transparent and partially exposed to daylight, with or without supplementary artificial light. The main advantage of cabinets is their compact size and relatively low cost. Cabinets suffer from the disadvantage that strict control of environmental conditions is lost when the doors are opened, although the effects of such brief variations may not be important.

Temperature-controlled rooms, with relatively low light intensities, such as are commonly used as animal houses and insectaries but also as dark rooms to house green plants at night.

Growth rooms, defined as places large enough to admit the operator (cf. cabinets above), and not exposed to daylight, but including provision of sufficient artificial light to enable green plants to make more or less normal growth for prolonged periods of time.

Glasshouses, which traditionally have been much used for research, but with limitations regarding control of the environmental factors that are now becoming more fully appreciated⁷.

Phytotrons, complex installations which include a series of growth rooms, temperature-controlled rooms, glasshouses and laboratories, providing a wide range of different controlled environments, in such a way that plants can be moved freely from one environment to another.

PLANTS AND THE WEATHER

Although controlled environments were first developed for fundamental work in plant physiology, they are now finding many uses in agronomic research. The most important is in the study of environmental effects, to show how and why the development and growth of plants are affected by factors of the weather. In the open, weather is so infinitely variable, unpredictable and complex, that it is most difficult to determine the effect which even one factor has had on the behaviour of a crop. Since the plant is affected simultaneously by a large number of factors, the use of controlled environments seems to offer the only serious prospect of separating the various effects. The most promising approach is to use environments in which all factors are controlled and not more than one or two are varied at once, so as to obtain results capable of confident interpretation in relation to the factors under study.

Work of this type is being carried out at several of the research institutes, and more is being planned, while a number of university departments are also working on such experiments in this field. The study of plant behaviour in controlled environments should be regarded as an essential stage in the process of working out the full effects of weather on crops, rather than as an end in itself. It is expected that this research will throw valuable light on the effects of weather on growth and yield, starting with relatively stable and simple sets of conditions with only one or two variables, but working towards more complex and variable types of environment.

The next step in building from this knowledge is likely to be the more detailed study of plant behaviour in the field, based on realistic measurements of the factors comprising the micro-climate and using the methods of growth analysis to provide a running commentary on the short-term effects of weather on growth. The introduction of electronic computers⁸ should now make it possible to calculate the interactions of all the complex factors that compose the natural weather in the field, a task which would have been virtually impossible without computers.

The final understanding of the responses of plants to the weather can, of course, come only from a study of the effects of environment at the biochemical level, but that is a field still virtually unexplored.

OTHER USES OF CONTROLLED ENVIRONMENTS

In addition to the study of weather effects, controlled environments are also finding many other valuable uses in research. For instance, some patterns of plant behaviour are due to changes in seasonal weather. It may be possible to study these patterns at only one time of the year if plants are grown out-of-doors, whereas by using suitable controlled environments it is possible to reproduce any particular seasonal condition, and so carry out experiments at any time of year, irrespective of natural season or weather. This has proved valuable in speeding up work on the phases of growth of fruit plants¹¹, and has also provided geneticists and plant breeders with a most valuable new technique⁹. In breeding it is often desirable to take plants as rapidly as possible through successive generations, it mattering little whether growth is "normal" so long as the plants produce viable seed. Once the effects of environment on each successive phase of development are understood, it is often possible to shorten the growing season to a fraction of its normal length and so greatly reduce the time taken by a generation from sowing to harvest, as is in fact being done with cereals at the Plant Breeding Institute. It is equally possible to slow down growth or to keep plants in the vegetative condition and prevent them from maturing, a technique that has useful applications in some types of genetical work with annuals and biennials. At the Welsh Plant Breeding Station controlled environments are being used for the rapid identification of genetic variations in strains of grasses. Other work of importance in this field is in progress at the Grassland Research Institute and the A.R.C. Unit of Experimental Agronomy at Oxford.

TESTING PLANT RESPONSES TO WEATHER

Another application of controlled environments in agronomic research is for the screening of new varieties. One of the basic requirements in crop husbandry is to choose varieties that are most likely to yield well under the particular, though largely unpredictable, weather conditions of the area concerned. It is essential that the chosen varieties should be able to survive the worst weather that may be experienced and thrive under the conditions that are most likely to occur. Trials out-of-doors may take several years to show whether a variety is suitable for a particular area, and many years before exceptional weather occurs to put the variety to the final test; but the initial screening of new varieties can be hastened by using controlled environments to test their capacity to yield well under certain conditions and to survive under others.

This method could be used, for instance, for assessing the resistance of perennial crop plants to "test" winters, or the ability of a variety of cereals to yield under short or long day conditions. It could also be used to find the minimum of cold required to break the winter dormancy of fruit buds, and so show by comparison with meteorological records, the geographical limits beyond which it would be useless to plant that particular crop. Controlled environments could also be used to compare the responses of new varieties with those of established types known to thrive in a particular district, thus helping in the planned production of new varieties "tailored" for defined climatic conditions.

CONTROLLING RESPONSES TO WEATHER

Although we are still far from a full understanding of the effects of weather on plant behaviour, work in controlled environments is showing how plants respond to certain isolated factors of the weather and will, no doubt, one day help to reveal the whole story. A fuller knowledge of this relationship should enable the plant's behaviour to be predicted under any set of weather conditions or, less usefully, to be explained in retrospect at the end of the season. A knowledge of environmental effects would also, of course, show how plant responses could be changed in any desired direction by altering the environment, but there seems little chance at present of controlling the critical environmental factors such as light and temperature on a field scale.

Although it may not be practicable to alter the behaviour of plants by changing their environment, recent work supported by the Council at the University of Nottingham has shown that it may be possible, by appropriate chemical treatment¹, to alter instead the plant's responses to the weather. This development is still in its infancy but might lead to significant applications in agricultural practice if it can be shown that judicious use of chemical regulators can prevent growth from being checked under marginal weather conditions. The use of such regulators could be successful only where the factors that limit growth are fully understood, since treatment of plants that are being checked by factors other than adverse weather might do more harm than good, so that the effective use of external regulators would require a subtle and well-informed approach.

DESIGN OF CONTROLLED ENVIRONMENT EQUIPMENT

These examples show a few of the ways in which crop yields might be increased by the application of knowledge that can be obtained most readily from experiments carried out in controlled environments. Recognition of the possibilities is likely to lead to increasing demand for the necessary equipment; but there is not yet any general agreement about the best design. Although there are now probably upwards of 200 growth rooms and cabinets in use in Britain, these vary greatly in size, convenience, degree of control and effectiveness. Many of them have been built by the staffs of the laboratories concerned, often with great ingenuity², but by trial and error, and the maintenance of these "home-made" facilities may sometimes be unnecessarily time-consuming or otherwise expensive. When allowance has been made for different requirements in different laboratories, it still seems that some degree of standardisation might well result in economies and greater efficiency in operation. The National Institute of Agricultural Engineering is therefore making a fundamental study of the characteristics of growth cabinets and rooms with a view to improvements in design that may contribute materially to advance in an important field of physiological research.

¹ GREGORY, F. G. 1921 and 1928. Studies in the energy relations of plants, I and II. *Ann. Bot.* **35**, 93 and **42**, 469.

² GREGORY, F. G. 1953. The control of growth and reproduction by external factors. *Rep. XIIIth. Int. Hort. Congress*, 1952, **1**, 96.

³ H.M.S.O. 1959. *Report of the Agricultural Research Council for the year 1957-58*. H.M.S.O. Cmd. 750.

⁴ HUDSON, J. P. 1957. *Control of Plant Environment for Experimental Work*. Univ. Nottingham Dept. Hort. Misc. Pub. 8.

- ⁵ HUDSON, J. P. 1957 (Ed.). *Control of the Plant Environment* (pp. 240). Butterworths Scientific Pub.
- ⁶ HUDSON, J. P. 1958. Effects of weather on plant behaviour. *Nature*, **182**, 1337.
- ⁷ LAWRENCE, W. J. C. 1957. The glasshouse as an environment for plant experiments, in *Control of the Plant Environment*. Butterworths Scientific Pub.
- ⁸ LONG, I. V. 1957. Instruments for micro-meteorology. *Quart. J. roy. met. Soc.*, **83**, 202.
- ⁹ THOMAS, P. T. 1957. Controlled environments in the study of plant genetics, in *Control of the Plant Environment*. Butterworths Scientific Pub.
- ¹⁰ WENT, F. W. 1957. *Experimental Control of Plant Growth*. Boston: Chronica Botanica.
- ¹¹ WILLIAMS, I. H. and HUDSON, J. P. 1959. Effects of environment on *Rubus idaeus*, I II, III and IV. *J. hort. Sci.*, **34**, 163, 170, 210 and 219.

RESEARCH STUDENTSHIPS AND FELLOWSHIPS

(a) RESEARCH STUDENTSHIPS

These studentships are intended to enable young graduates who wish to make a career in agricultural research either to take a further course of study, or to undertake a specific research project under supervision as a means of training in research methods, or to read for a veterinary degree in order to equip themselves for research in fields in which this added qualification is likely to be of particular advantage. They are open to honours graduates in science or those holding a veterinary qualification and to graduates in agriculture or horticulture who have shown special interest in one of the basic sciences.

The following twenty-six awards were made in 1958 :—

<i>Name</i>	<i>Place of Tenure</i>	<i>Subject</i>
R. C. Cooke ...	Birmingham University ...	Plant Pathology
B. H. Davies ...	Liverpool University ...	Biochemistry
E. E. Donahaye ...	London University ...	Entomology
A. V. Edwards ...	Cambridge University ...	Veterinary Studentship
K. J. R. Edwards ...	University College, Aberystwyth...	Plant Breeding
M. A. Foster ...	Oxford University ...	Biochemistry
M. W. Goldsmith ...	London University ...	Animal Physiology
W. A. Hamilton ...	Glasgow University ...	Biochemistry
M. J. K. Harper ...	Unit of Reproductive Physiology and Biochemistry	Reproductive Endocrinology
A. C. Hastie ...	Rothamsted Experimental Station	Plant Pathology
Miss H. E. Hein ...	Glasgow University ...	Animal Pathology
R. A. Hiller ...	London University ...	Plant Physiology
M. W. Johnson ...	A.R.C. Virus Research Unit ...	Biochemistry
D. L. Laidman ...	Liverpool University ...	Biochemistry
J. N. Lythgoe ...	Cambridge University ...	Plant Pathology
D. S. Madge ...	Rothamsted Experimental Station	Entomology
T. S. Mansfield ...	Reading University ...	Plant Physiology
J. R. Morton ...	Cambridge University ...	Animal Genetics
J. Noble-Nesbitt ...	Cambridge University ...	Insect Physiology
D. A. Rose ...	Rothamsted Experimental Station	Soil Physics
D. H. Steven ...	Cambridge University ...	Veterinary Studentship
J. M. Webster ...	London University ...	Plant Nematology
G. M. Weir ...	Oxford University ...	Plant Physiology
F. G. Whitelaw ...	Rowett Research Institute ...	Animal Nutrition
S. F. Buck ...	Rothamsted Experimental Station	Statistics
J. D. O'Shea ...	Royal Veterinary College ...	Animal Pathology

At 31st March, 1959, the number of students in training was 70, divided amongst the different disciplines as follows:—

<i>Botany</i>	<i>Chemistry</i>	<i>Entomology</i>	<i>Statistics</i>	<i>Zoology and Veterinary Science</i>
22	16	13	1	18

(b) FELLOWSHIPS

Up to three Junior Agricultural Research Fellowships, tenable for a maximum period of three years, are available annually.

Those current at 31st March, 1959, were :—

Miss M. R. Lunt, B.A.	... Oxford University	... Investigation of aspects of carbohydrate metabolism in arthropods, with particular reference to the formation of cuticular polysaccharides.
J. G. Shoesmith, B.Sc., Ph.D.	Manchester University	Research on the biochemical aspects of bacterial motility.
W. D. Stein, M.Sc.	... London University	... Research on the mechanism of facilitated diffusion in the red blood cell.

Veterinary Research Fellowships, tenable for three years, are available to veterinary graduates with not less than three years' post-graduate experience who wish to continue their researches for a further period before seeking a post. No awards were made during the year under review.

SPECIAL RESEARCH GRANTS

During the period covered by this Report the Council has continued to make grants to Universities, Colleges and other organisations, to assist in research projects on subjects of interest to the Council. Grants are normally limited to three years but occasionally they are made for longer periods.

The grants current on 31st March, 1959, were as follows:—

1. ABERDEEN UNIVERSITY

Department of Biological Chemistry

The metabolism of nitrifying bacteria.

2. ABERYSTWYTH, UNIVERSITY COLLEGE OF WALES

(i) *Department of Agriculture*

The variations in the moisture content of cut herbage material under varying conditions of temperature and humidity.

(ii) *Department of Agricultural Botany*

A comparative biochemical assessment of specific genotypes of herbage grasses in relation to their physiological characteristics.

3. BANGOR, UNIVERSITY COLLEGE OF NORTH WALES

(i) *Department of Agricultural Botany*

The mineral nutrition of certain races of wild white clover.

(ii) *Department of Agricultural Chemistry*

(a) The metabolism of herbicides by soil bacteria.

(b) The biochemical and nutritive properties of pasture.

(c) Research on bracken poisoning of cattle.

4. BIRMINGHAM UNIVERSITY

Department of Botany

(a) The inheritance of frost resistance in the potato.

(b) a taxonomic investigation of the tuber-bearing *Solanums*, using serological and other techniques.

5. BRISTOL UNIVERSITY

(i) *Department of Animal Husbandry*

The nutrition of the baby pig.

(ii) *Department of Physiology*

Research on bovine acetonaemia.

(iii) *Department of Veterinary Anatomy*

Problems of avian respiration.

(iv) *Department of Veterinary Medicine*

The experimental transmission of lymphoid leukaemia.

6. CAMBRIDGE UNIVERSITY

(i) *School of Agriculture*

- (a) The carcass quality of beef.
- (b) A study of soil-borne plant pathogenic fungi.

(ii) *Department of Animal Pathology* Respiratory diseases in poultry.

(iii) *Department of Biochemistry*

- (a) The biochemistry of chloroplasts in relation to photosynthetic phosphorylation.
- (b) The organisation and chemical composition of plant cell walls during growth.
- (c) The biochemistry of the uterus.
- (d) Research on tea fermentation. (The money for this grant is provided by the Nyasaland Tea Association.)

(iv) *School of Botany*

The growth and form of an annual plant as a function of environmental conditions.

(v) *Department of Colloid Science*

The surface properties of cells.

(vi) *Department of Pathology*

- (a) Immunological and serological research. (A block grant made jointly with the Nuffield Foundation.)
- (b) Research on blood groups of the pig.

(vii) *Physiological Laboratory*

The secretion of progesterone by the adrenal glands.

(viii) *Department of Veterinary Clinical Studies*

- (a) Neonatal mortality and haemolytic diseases among animals.
- (b) the sow's mammary gland in health and disease.
- (c) Climatic conditions in "broiler" chicken houses.
- (d) Research on pyelonephritis in pigs.
- (e) Piglet mortality, with special reference to transmissible gastro-enteritis.

7. DURHAM UNIVERSITY (KING'S COLLEGE, NEWCASTLE-UPON-TYNE)

(i) *School of Agriculture*

- (a) Studies of pig farrowing accommodation. (A long-term grant.)
- (b) The progeny testing of cattle for meat and milk production.
- (c) The restoration of opencast coal sites.

(ii) *Department of Chemistry*

The mechanism of melanin formation.

(iii) *Department of Zoology*

A comparative study of the cytology of the genus *Heterodera*.

8. EDINBURGH UNIVERSITY

- (i) *Departments of Agriculture and Chemistry*
Research on grass conservation.

(ii) *Department of Animal Genetics*

- (a) The genetics of beef and milk production in dual purpose cattle.
(b) Fertilisation and early embryonic development in animals.

(iii) *Department of Zoology*

- (a) The immature stages in *Trichostrongylus*.
(b) Research on insect cell culture.

9. GLASGOW UNIVERSITY

(i) *Department of Genetics*

The genetics of hydrolases.

(ii) *Department of Veterinary Medicine*

- (a) Research on Johne's disease.
(b) The pathology of pneumonia in pigs.
(c) Immunological studies in young domestic animals.
(d) Electrolyte and body fluid changes in calf diarrhoea (White Scours syndrome).
(e) The urinary changes associated with electrolyte changes in body fluids.

10. HARPER ADAMS AGRICULTURAL COLLEGE

- (a) Pig husbandry investigations.
(b) Poultry husbandry investigations.

11. HOUGHTON POULTRY RESEARCH STATION

Avian physiology.

12. LEEDS UNIVERSITY

(i) *Department of Agriculture*

The nutrition of the pregnant sow.

(ii) *Department of Botany*

The structure of the cell wall of apple fruit and "rubbery wood" of apple trees (in collaboration with East Malling Research Station).

(iii) *Department of Biochemistry*

A study of the enzyme systems in insects responsible for the activation of organo-phosphorus compounds into anti-cholinesterases.

13. LIVERPOOL UNIVERSITY

(i) *Department of Veterinary Anatomy*

The nervous and vascular mechanisms involved in semen production.

(ii) *Department of Veterinary Preventive Medicine*

Research on respiratory diseases in poultry.

14. LONDON UNIVERSITY

BIRKBECK COLLEGE

Department of Physics

The molecular structure of viruses.

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY

(i) *Department of Zoology and Applied Entomology*

Research on insect ecology. (A five-year block grant.)

(ii) *Departments of Zoology and Applied Entomology, and Botany*

The action of fumigants on seed-borne fungi.

KING'S COLLEGE

Department of Zoology

(a) Studies of *Fasciola hepatica* and other trematodes.

(b) Research on tick and other arthropod-borne diseases.

LISTER INSTITUTE OF PREVENTIVE MEDICINE

Department of Biochemistry

The mechanism of starch-carbohydrase action.

QUEEN MARY COLLEGE

Department of Botany

Research on photosynthesis.

ROYAL VETERINARY COLLEGE

(a) The relation between climatic environment and productivity in poultry.

(b) Extra-chromosomal influences in development and heredity.

(c) Gustatory senses in cattle.

UNIVERSITY COLLEGE

(i) *Department of Biochemistry*

The biochemistry of lactation.

(ii) *Department of Botany*

The metabolism of certain newer amino and imino acids by soil micro-organisms.

WYE COLLEGE

(a) The effect of water and nitrogen on the growth of apple trees.

(b) Research on pig breeding.

(c) Poultry research. (A long-term grant.)

15. LONG ASHTON RESEARCH STATION

Research on blackcurrent gall mite.

16. NATIONAL VEGETABLE RESEARCH STATION

The effect of sub-lethal doses of herbicides on vegetable crops.

17. NORTH OF SCOTLAND COLLEGE OF AGRICULTURE

The control of gangrene, blackleg and soft rot in potatoes.

18. NORTHERN POULTRY BREEDING STATION

Poultry research.

19. NOTTINGHAM UNIVERSITY

(i) *Department of Agriculture*

Research on oestrogen metabolism in sheep and cattle.

(ii) *Department of Agricultural Botany*

The development of buds of the potato tuber.

(iii) *Department of Horticulture*

(a) The germination of *Orobanche*.

(b) The diagnosis of damage from spray drift.

(c) The water relations of tomato plants grown in heated glass-houses, with special reference to methods of controlling irrigation.

(d) Methods of controlling the responses of plants to environmental conditions.

20. OXFORD UNIVERSITY

(i) *Department of Agriculture*

(a) Isotopic studies of root uptake from the soil and culture solutions.

(b) Mechanisms of peptide formation.

(ii) *Department of Botany*

(a) The ability of plant nuclei to respire.

(b) The resistance of oats to certain diseases.

(c) The breeding systems in flowering plants.

(iii) *Department of Pharmacology*

Plasma enzymes in the ruminant.

(iv) *Department of Zoology*

The comparative behaviour of weaver finches.

21. READING UNIVERSITY

(i) *Department of Agriculture*

(a) Poultry husbandry investigations. (A long term grant.)

(b) The effects of age at castration on identical twin calves reared for beef and milk production.

(ii) *Department of Agricultural Botany*

The physiological and ecological aspects of crop growth.

(iii) *Department of Agricultural Chemistry*

Variations in shell characteristics over different parts of the hen's egg shell.

(iv) *Department of Horticulture*

(a) The bulbing of onions.

(b) The effects of external conditions on the developmental physiology of the carnation.

(v) *Department of Microbiology*

The nutrition and metabolism of pleuropneumonia-like organisms.

22. ROTHAMSTED EXPERIMENTAL STATION

(a) Insecticide investigations. (The money for this grant is provided by the Colonial Office.)

(b) The nutrition of forest trees in nurseries. (The money for this grant is provided by the Forestry Commission.)

(c) Pyrethrum research. (The money for this grant was provided originally by the Colonial Office and is now provided by the Department of Scientific and Industrial Research.)

(d) The rental and maintenance of the electronic computer in the Statistical Department.

(e) The succession of fungi in mouldy hay.

23. ROWETT RESEARCH INSTITUTE

The absorption and elimination of natural and radioactive isotopes of calcium, strontium and barium in sheep.

24. SHEFFIELD UNIVERSITY

(i) *Department of Microbiology (A.R.C. Unit of Microbiology)*
The growth of micro-organisms.

(ii) *Department of Zoology*
Research on comparative endocrinology.

25. SWANSEA, UNIVERSITY COLLEGE

Department of Botany

(a) Studies of the organic and inorganic nutrients in *Eriophorum vaginatum* L.

(b) A study of the resting bodies formed by various species of *Verticillium*.

26. WEST OF SCOTLAND AGRICULTURAL COLLEGE

(a) Pig farrowing house experiment.

(b) The movement of plant growth regulators and other herbicides in bracken.

27. OTHER ORGANISATIONS AND INDIVIDUALS

(i) *Animal Health Trust*

Farm Livestock Research Centre

The incidence of *Salmonellae* in the lymph nodes of pigs.

- (ii) *Electrical Research Association*
 - (a) Crop conservation and storage.
 - (b) Farm machinery and equipment.
 - (c) Electricity in livestock husbandry.
 - (d) Electricity in horticulture.
 - (e) Specialised applications of electricity.
- (iii) *Essex Institute of Agriculture*

The effect of the number of sprouts per set on the yield and grading of main crop potatoes.
- (iv) *Kesteven Farm Institute*

Broiler nutrition.
- (v) *The Polytechnic, London*

The biological control of eelworms by means of predacious fungi.
- (vi) *Private A.I. Centres' Group*

Infertility in cattle.
- (vii) *C. B. Williams, M.A., Sc.D., F.R.S.*

The relations between weather conditions and insect activity and insect population.

SOIL

ROTHAMSTED EXPERIMENTAL STATION

Harpenden, Herts.

Director: F. C. BAWDEN, M.A., F.R.S.

Deputy Directors: A. Muir, Ph.D.
F. Yates, Sc.D., F.R.S.

PHYSICS

Head of Department: H. L. Penman,
Ph.D., F.Inst.P.
G. H. Cashen, M.Sc.
I. F. Long
J. L. Monteith, Ph.D., D.I.C., A.Inst.P.

PEDOLOGY

Head of Department: A. Muir, Ph.D.
C. Bloomfield, Ph.D., F.R.I.C.
G. Brown, B.Sc.
R. Greene-Kelly, Ph.D.
I. Stephen, Ph.D.

SOIL MICROBIOLOGY

Head of Department: P. S. Nutman,
Ph.D., A.R.C.S.
R. M. Jackson, B.Sc.
Mrs. Janina Kleczkowska, Ph.D.
Jane Meiklejohn, Ph.D.
F. A. Skinner, Ph.D.
N. Walker, Ph.D., F.R.I.C.

BIOCHEMISTRY

Head of Department: N. W. Pirie, M.A.,
F.R.S.
G. N. Festenstein, Ph.D.
Margaret Holden, B.Sc.
R. H. Kenten, B.Sc.
P. J. G. Mann, Ph.D.

CHEMISTRY

Head of Department: G. W. Cooke,
Ph.D., F.R.I.C.
P. W. Arnold, Ph.D.
Blanche Benzian, B.Sc.
J. M. Bremner, Ph.D.
J. K. R. Gasser, M.Sc., A.R.I.C.
Signe G. Heintze, M.Phil.
G. E. G. Mattingley, Ph.D.
H. A. Smith
O. Talibudeen, Ph.D.
R. G. Warren, B.Sc.
F. V. Widdowson, B.Sc.(Agric.)

TROPICAL SOILS ADVISER

H. Greene, D.Sc.

BOTANY

Head of Department: D. J. Watson, Ph.D.
E. C. Humphries, D.Sc.
Gillian N. Thorne, Ph.D.
Joan M. Thurston, B.Sc.

PLANT PATHOLOGY

Head of Department: P. H. Gregory,
D.Sc., D.I.C.
E. W. Buxton, Ph.D.
Mary D. Glynnne, D.Sc.
J. M. Hirst, D.Sc., Ph.D.
B. Kassanis, D.Sc.
A. Kleczkowski, M.D., Ph.D.
I. Macfarlane, Ph.D.
H. L. Nixon, M.A.
G. A. Salt, Ph.D.
Mrs. Marion A. Watson, Ph.D.

NEMATOLOGY

Head of Department: F. G. W. Jones, M.A.
C. C. Doncaster, B.Sc.
Mary T. Franklin, Ph.D.
J. B. Goodey, Ph.D.
J. J. Hesling, B.Sc., A.R.C.S.
H. R. Wallace, Ph.D.
R. D. Winslow, B.Agr., Ph.D.

ENTOMOLOGY

Head of Department: K. Mellanby,
C.B.E., Sc.D., Ph.D.
C. J. Banks, Ph.D.
H. F. Barnes, Ph.D.
R. M. Dobson, Ph.D.
C. G. Johnson, D.Sc.
D. B. Long, Ph.D.
F. Raw, Ph.D.

STATISTICS

Head of Department: F. Yates, Sc.D.,
F.R.S.
D. A. Boyd, Ph.D.
B. M. Church, B.Sc.
J. H. A. Dunwoody, B.A.
M. J. R. Healy, B.A.
F. B. Leech, B.Agr., M.R.C.V.S.
S. Lipton, M.Sc.
H. D. Patterson, M.Sc.
D. H. Rees, B.Sc.

DUNHOLME FIELD STATION

Head of Station: R. Hull, Ph.D.
S. N. Adams, D.Phil.
R. A. Dunning, Ph.D.

INSECTICIDES AND FUNGICIDES

Head of Department: C. Potter,
D.Sc., D.I.C.
P. E. Burt, B.A.
M. Elliott, Ph.D.

F. T. Last, Ph.D., D.I.C., A.R.C.S.
K. A. Lord, Ph.D., A.R.I.C.
A. H. McIntosh, Ph.D.
J. Ward, B.Sc.
M. J. Way, M.A.

Secretary: J. B. Bennett, F.C.A.

BEE RESEARCH

Head of Department: C. G. Butler, Ph.D.
L. Bailey, Ph.D.
J. B. Free, Ph.D.
J. Simpson, Ph.D.

FIELD EXPERIMENTS

Head of Department: H. V. Garner,
O.B.E., M.A.
G. V. Dyke, M.A.

ROTHAMSTED AND WOBURN FARMS

Head of Farms: J. R. Moffatt,
B.Sc.(Agric.), N.D.A., A.I.B.A.E.

Librarian: D. H. Boalch, M.A., F.S.A.

On 31st March, 1959, the scientific and experimental staff of the Station numbered 163.

CURRENT WORK

Most problems of arable agriculture, except plant breeding, are studied at Rothamsted Experimental Station, and the names of the various departments indicate the scope of the work. Of the many lines of research described in the Annual Report of the Station for 1958, those mentioned here are mainly ones with results bearing directly on agricultural practice.

Soils and Fertilizers. On the heavy soil at Rothamsted organic matter affects the growth of crops mainly by affecting the supply of plant nutrients. Even such sensitive crops as carrots and beetroot respond to differences in soil structure only briefly after germination. Applications of straw and composted straw affected the yield of crops to which they were directly applied by supplying potassium and withdrawing nitrogen from circulation, and the effects of past dressings of straw derived from the residues of nitrogen and potassium.

Work on the trouble in sugar beet, known as "Docking Disorder", indicates the much greater importance of organic matter in some light soils. This trouble, characterised by slow growth caused by the main roots dying, was unusually prevalent in 1958, but only on light, alkaline soils containing little or no clay or organic matter. Mineral fertilizers do not control it, but organic manures and the taking of leys do. Inadequate aeration may be one cause of poor growth in these almost structureless soils, and methods to measure aeration are being developed.

The ley-arable experiment shows how organic matter and plant nutrients change when old grassland is ploughed and when leys are introduced into an arable rotation. On Highfield, previously permanent grass and rich in humus, one-seventh of the organic matter was lost after 6 years of arable cropping, and the loss was not lessened by growing a ley for 3 of these years. On Fosters Field, old arable land containing much less organic matter than Highfield, 3 years under ley followed by 3 years arable cropping raised the organic matter by one-seventh, twice the increase obtained by ploughing in 26 cwt. of straw/acre annually for 18 years. Continued cutting and removing grass or lucerne depletes potassium, and yields of arable crops fall unless it is replenished.

The current value of potassium and phosphorus reserves built up by past manuring was measured by growing six crops on the Exhaustion Land Experiment. The residual phosphate from manures applied between 1856 and 1901 gave full crops of cereals, sugar beet and swedes in 1957, but not in 1958; in neither year was it enough for potatoes or kale. The residual potassium was enough for cereals, sugar beet and swedes in both years, but not for potatoes in either year or for kale in 1957. Even the land unmanured for over 100 years contained enough potassium for cereals, sugar beet and swedes in the conditions of 1957, but in 1958 swedes and beet responded to the fresh dressings.

A series of fourteen experiments on the nitrogen manuring of spring-sown wheat and barley ended in 1958. Both crops gave profitable increases in yield with 3-4 cwt. "Nitro-Chalk"/acre at Rothamsted and up to 6 cwt./acre at Woburn. Wheat at both farms, and barley at Rothamsted, responded most when all the dressing was given before drilling, but at Woburn barley did slightly better with an early top dressing. Dividing the dressing, or giving a late top dressing, gave no benefit. Heavy dressings of ammonium sulphate were combine-drilled with the seed without affecting germination, and this method gave higher yields than broadcasting the fertilizer at sowing time. Except when crops lodged, winter wheat responded better to nitrogen given in March than when given to the seed-bed or in May. Whether applied as solids or in solution, ammonium sulphate, ammonium nitrate, calcium nitrate and urea all greatly increased yields of old pasture and newly sown ryegrass. An aqueous solution of ammonia damaged permanent grass and failed to increase yield; when applied before sowing ryegrass, it increased yield less than did the other sources of nitrogen. All the fertilizers increased the amounts of water-soluble ammonium—and nitrate-nitrogen in grass, which may be important in affecting the health of animals that eat it.

A clue towards understanding the curious behaviour of molybdenum in "teart" soils was provided by the behaviour of this element in the presence of iron oxide. In waterlogged soils molybdenum is strongly fixed to iron oxide, but is readily released on incubation with decomposing remains of plants.

New chemicals are constantly introduced into agriculture, and it is important to know whether they accumulate in the soil. Fortunately, most seem to be susceptible to microbial attack, but the sex hormone stilboestrol disappears from soil rather slowly compared with the weed-killer, 2:4-D. A small dose of 2:4-D added to soil changes the flora to one better able to decompose it, and large doses increase the numbers of active bacteria.

Opportunities to study the anaerobic decomposition of cellulose were improved by isolating a pure culture of a bacterium, provisionally identified as *Clostridium cellobioparum*, able to do this in pure culture. It breaks down cellulose and produces organic acids, sugars, hydrogen and carbon dioxide, but not methane.

Botany and Biochemistry. Differences in yield between individual crops of one kind often depend on differences in leaf area, so substances that affect leaf area could affect yield. Gibberellic acid is such a substance, and in 1957 it increased the yield of potatoes. In 1958 it again consistently

increased leaf area, but it increased yield only within a restricted range of conditions. When potatoes were treated frequently, and particularly when nitrogen was limiting, photosynthesis was so affected that yield was decreased. Extracts of expanding French-bean leaves contained a substance behaving like gibberellic acid on paper chromatograms and in its ability to accelerate the growth of discs of etiolated leaf. Its amount was correlated with the rate at which the leaves were expanding, so it seems to be a normal growth regulator of this plant.

The movement of carbon dioxide into a field crop by day from photosynthesis, and out by night from respiration was correlated with the increase in dry matter in the crop in August and September. In October a flux from air to crop was detectable only in bright sunshine, and there is a suggestion that at some other daytime periods the crop may have been getting its carbon dioxide from the soil.

Seeds of wild oats persist under temporary leys much longer than when arable crops are grown; many seeds survive for more than 4 years, so short-term leys are evidently no answer to heavy infestations. No evidence was found to support the idea that couch grass exudes substances into soil that are toxic to crops, although it was confirmed that dried roots and rhizomes contain substances that inhibit germination and growth of seedlings.

Biochemical work on the blackening of potato tubers supported the idea that the pigment responsible is a complex of ferric iron and dihydroxy phenols, produced when colourless ferrous complexes oxidize in air. Blackening is also affected by the amount of citrate in tubers; this and other substances that form colourless iron complexes prevented blackening when added to water in which the tubers were boiled. Potatoes from Woburn blackened less than those from Rothamsted, where blackening varied more with the kind of manuring.

Methods of extracting and preparing leaf protein for human consumption were improved, and encouraging yields were obtained from a range of plants; of spring-sown cereals, oats were the most productive and gave 471 lb. of protein/acre when cut in June. However, plants that now contribute nothing to human nourishment may find a use through this process, for nettles growing wild, except for a small dose of fertiliser, yielded 546 lb. of protein/acre.

Pests and diseases. The weather in 1958 favoured fungus diseases but not pests; virus diseases also spread much less than in 1957, for although early in the season it seemed that aphids might again be abundant, the weather later turned against them, and their predators were also plentiful. After the great losses from sugar beet yellows in 1957, a regular survey was organised from Dunholme, and warnings of the need to spray were issued when aphids averaged one per four plants in any district. As a result, 100,000 acres were sprayed, and in September yellows was much less prevalent in sprayed than in comparable unsprayed crops. In some districts yellows was not serious enough to affect yields, but in others spraying increased yield by amounts up to 5 tons of roots/acre.

The health of seed tubers saved from potato experiments in 1957 showed that, despite the unprecedentedly early heavy aphid attacks that

year, spraying with insecticides completely stopped the spread of leaf roll. Spraying did not prevent the spread of rugose mosaic, but this, fortunately, is less important than leaf roll. The practical value of insecticides in controlling the common virus diseases of sugar beet and potatoes now seems established.

Organophosphorus insecticides are generally considered to act by affecting cholinesterases, and most of them do affect these enzymes. However, that it may not be the only way all of them act was suggested by the fact that poisoning house flies with "Diazinon" had no effect on the cholinesterase activity of their brains. The mechanism whereby flies become and remain resistant to "Diazinon" seems to differ with different strains: one resistant strain remained resistant from generation to generation without being continually exposed to the poison, whereas another remained resistant only when each generation was exposed. Continuing work on pyrethrins and related compounds gave further information on the relation between chemical structure of molecules and their insecticidal activity, and suggested that crude extracts of pyrethrum contain insecticidal substances other than those previously recognised. Some substances were found to enhance the valuable "knock-down" action of pyrethrins.

The common virus disease of cereals, yellow dwarf, which is particularly damaging in oats, seems to be caused by at least two viruses, each of which occurs in strains of different virulence. Leaf-hoppers infected with wheat striate mosaic virus produced fewer young than uninfected ones, and many of the eggs they laid failed to hatch; this is the first unequivocal evidence of a plant virus harming the insect that transmits it. Strains of potato virus Y normally not transmitted by aphids became so when multiplying in plants simultaneously infected with strains that are aphid-transmitted.

In the favourable conditions for spread of potato blight there was little difference between the dates at which four potato varieties, reputedly of different susceptibilities, became defoliated. However, varieties did differ in the extent to which their stems became invaded by the fungus and to which lesions on their leaves produced spores. A new method of spread from infected tubers was noted in this wet year. In addition to lesions developing on stems growing from infected tubers, the fungus spread through soil from infected tubers that produced no shoots and infected the lowest leaves of nearby plants growing from uninfected tubers.

Eyespot and take-all of cereals were also unusually severe in 1958. The high incidence of eyespot made lodging even more serious than it otherwise would have been and contributed to the low yields; on the Rothamsted six-course rotation experiment, for example, the wheat was 100 per cent infected, lodged early, and the yield was 18.7 cwt./acre compared with the previous 20 years' average of 30.4. Take-all was particularly severe when winter wheat followed another wheat or barley crop, but was negligible after oats. The incidence of mildew on Broadbalk was correlated with manuring and was increased by lack of potash.

Field trials with ninety pea varieties showed that more than half of them, including many that are popular and widely grown in the United Kingdom, are highly susceptible to fusarium wilt. Some of these varieties

are resistant in other countries, suggesting we have strains of the fungus not yet in those countries. Fortunately, many were resistant, but the fungus varies and varieties cannot be relied on to remain resistant indefinitely.

Most pathogens vary in pathogenicity, nematodes no less than fungi. Strains of potato-root eelworm that infect potatoes at first thought to be resistant are now known to occur commonly, and some beet eelworms develop in *Beta patellaris*, previously considered not to be a host of this pest. Thus resistant varieties cannot be relied on to control eelworms, and other ways of decreasing damage are being sought, such as by varying crop rotations, or methods of cultivation, and by soil treatments. New information about the factors affecting the movement of eelworms through soil and over plants was obtained, and progress was made in isolating the substance exuded by potato roots that causes cysts of the root eelworm to hatch.

Bees. Improving methods for assaying "queen substance" provided new information about this important material. It is produced in the queen's mandibular glands, from where she apparently distributes it over her body while grooming and makes it obtainable by her workers. It inhibits workers from raising queens, and, when given to queenless workers, inhibits the development of their ovaries. Queens that have been superseded or have swarmed from uncrowded colonies contain less of the substance than those in colonies of the same size with only one queen, a clear suggestion that the substance could have important applications in colony management.

Observations in years with very different nectar-flows show that acarine disease is inversely correlated with amount of nectar. Antibiotics suppressed European Foul Brood, and fumigating with formaldehyde or acetic acid gave promising results in freeing comb from contaminating bacteria.

The increasing use of insecticides on crops is dangerous to bees, and tests on dead bees from various districts showed that some had been killed by parathion, some by DDT and some by arsenic.

Statistics. Statistical work again was concerned with far more than Rothamsted's experiments, and results were analysed for many other research stations and organisations, both at home and in various Commonwealth countries. A major task was the summarising of 230 fertiliser experiments, each of twenty-seven plots, made on rice farms in Bihar, India. The survey of fertiliser practice was continued and extended, and other large surveys organised were of the growing of maincrop potatoes and of diseases in dairy cows.

THE MACAULAY INSTITUTE FOR SOIL RESEARCH

Craigiebuckler, Aberdeen

Director: A. B. STEWART, M.A., B.Sc., Ph.D., F.R.I.C., F.R.S.E.

Deputy Director: R. L. Mitchell, B.Sc., Ph.D., F.R.I.C., F.R.S.E.

PEDOLOGY

Head of Department: R. C. Mackenzie,

D.Sc., Ph.D., F.R.I.C.

W. A. Mitchell, B.Sc.

(Soil Mineralogy)

B. D. Mitchell, B.Sc., A.R.I.C.

(Physical Chemistry)

R. A. Robertson, B.Sc.

(Peat Ecology)

T. W. Wright, B.Sc.(For.), Ph.D.

(Forest Soils)

W. O. Binns, M.A., B.Sc.(For.), Ph.D.

(Forest Soils)

H. G. M. Hardie, B.E.M., Ph.D., A.R.I.C.

(Soil Analysis)

SPECTROCHEMISTRY

Head of Department: R. L. Mitchell, B.Sc.,

Ph.D., F.R.I.C., F.R.S.E.

R. O. Scott, B.Sc., Ph.D., A.R.T.C., A.R.I.C.

V. C. Farmer, B.Sc., Ph.D.

D. J. Swaine, M.Sc., Ph.D., F.R.A.C.I.

A. M. Ure, B.Sc., Ph.D.

BIOCHEMISTRY

Head of Department: J. S. D. Bacon,

M.A., Ph.D.

R. B. Duff, B.Sc., Ph.D.

R. I. Morrison, B.Sc., Ph.D., F.R.I.C.

PLANT PHYSIOLOGY

Head of Department: P. C. deKock, M.Sc.,

D.Phil.

W. M. Crooke, B.Sc., Ph.D., A.R.I.C.

A. H. Knight, B.Sc., A.R.I.C.

(Radioactivity)

MICROBIOLOGY

Head of Department: D. M. Webley, M.Sc.,

Ph.D.

SOIL FERTILITY

Head of Department: E. G. Williams,

B.Sc., Ph.D.

J. W. S. Reith, B.Sc.(Agr.), Ph.D., A.R.I.C.

G. Anderson, B.Sc., Ph.D.

STATISTICS

Officer-in-Charge: R. H. E. Inkson,

B.Sc., F.R.S.S.

Secretary: Miss E. J. Dey *Librarian:* Miss A. M. B. Geddes, M.A., F.L.A.

Founded in 1930, through the generosity of the late Dr. T. B. Macaulay of Montreal, the Macaulay Institute has as one of its primary objects the acquisition of such information on the soils of the country as will be of assistance to the farmer, the forester and others interested in soil and land use. In particular, by adding to the basic knowledge of soils and the needs of crops it is the aim of the Institute to help towards the efficient maintenance and improvement of soil fertility from the standpoint of both crop production and animal requirement.

On 31st March, 1959, the scientific and experimental staff of the Institute numbered sixty-seven.

CURRENT WORK

In the Department of Pedology the examination of soil clays has been greatly facilitated by the installation of a Raymex 60 X-ray generator. Mineralogical studies of clay and fine sand fractions have been extended and interesting results have been obtained on the mineralogical aspects of phosphate fixation in soils. The techniques of differential thermal analysis have been applied to a range of soil clays, both from this country and from overseas, and useful information has also been obtained on the fundamental character of various peats and their fractions. Field research on peat has been concerned primarily with the study of water relationships. Studies are also being made of the rooting habits of natural bog plants and sown species on deep peat and the effect of the rooting

systems of different species of grasses and clovers on peat structure. Pollen studies have been continued, as have the chemical, physical and microscopical examinations of a wide range of peat samples. The effects of tree growth on the physical and chemical properties of deep peat have been further investigated and other work has included the examination of forest soils and, from the analysis of foliage samples, the establishment of concentration ranges for the diagnosis of major nutrient deficiencies in relation to tree growth.

In the Department of Spectrochemistry there has again been a considerable increase in the number of samples of soils and plant materials on which trace element determinations have been carried out. As in the past, these samples have been studied mainly in relation to problems of crop production or animal health. The development of spectrochemical techniques applicable to direct reading equipment has been continued, with particular emphasis on methods using rotating disk electrodes incorporating plant ash samples. The construction of a modified version of the electronic scanning cathode ray microphotometer is well advanced. Investigations using infra red and ultra violet absorption methods have been concerned chiefly with the constitution and genesis of soil organic matter and peat, a problem which is also being tackled by other departments in the Institute.

In the Departments of Biochemistry, Plant Physiology and Microbiology, closely integrated studies have been made of humic acids and the hydrolysis products of a water soluble polysaccharide fraction from peat, as well as of various organic components of healthy and unhealthy plants and of plants grown at various nutritional levels of iron, potassium, calcium, phosphorus and nitrogen. Bacterial isolates soil and the rhizosphere have been shown to produce 2-ketogluconic acid which chelates calcium strongly and so helps to make certain minerals which are difficult to get into solution, more available to plants. A feature of the plant physiological work has been the investigation of the biochemical mechanism underlying mineral changes associated with iron deficiency chlorosis. Other results obtained indicate that there is a relationship between cation exchange capacity in a plant and the pectin content of the root. Salt absorption studies with disks of various root crops have shown that each tissue has its characteristic pattern. Studies of the microbiology of the root region, actinomycetes and fungi, have also been extended.

Field, pot and laboratory investigations by the Department of Soil Fertility have been continued to define the nutrient requirements of different crops and to clarify the significance of soil properties and pedological factors in manurial practices. Useful results have been obtained in the identification of nucleic acid derivatives in soil humic acid as well as in such more immediately practical problems as the manuring of potatoes, fertiliser placement for swedes and turnips and the time of application of nitrogen for oats. A study of the relationships between carbon, nitrogen, sulphur and organic phosphorus in different soil types has also yielded interesting results.

The Statistics Section has again collaborated closely in the design of experiments and the analysis of results, both within the Institute and in

collaboration with other research organisations. In the Library the aim continues to be to build up a good representative stock covering the field of soil science and related subjects and to co-operate in the national inter-library loan schemes.

More detailed accounts of the investigations in progress and particulars of published work will be found in the Institute's Annual Report.

SOIL SURVEY OF GREAT BRITAIN

England and Wales

Rothamsted Experimental Station, Harpenden, Herts.

Head of Survey: A. MUIR, B.SC., Ph.D.

Deputy Head: D. A. Osmond, M.SC., Ph.D., A.R.I.C.

G. D. Ashley, B.SC.
B. W. Avery, B.SC.
A. Crompton, B.SC.
D. C. Findlay, B.A.
B. R. Hall, B.SC.
C. A. H. Hodge, B.SC.

R. A. Jarvis, B.SC., F.R.G.S.
D. W. King, B.SC., A.R.I.C.
H. H. le Riche, B.SC., Ph.D.
D. Mackney, B.SC.
C. W. Montgomery, B.A.
R. S. Seale, M.A.

Scotland

Macaulay Institute for Soil Research, Craigiebuckler, Aberdeen

Head of Survey: R. GLENTWORTH, B.S.A., Ph.D.

J. W. Muir, B.SC.(Agr.), A.R.I.C., N.D.A., N.D.D.

E. L. Birse, B.SC.
R. Grant, M.A., B.SC.
D. Laing, B.SC., A.R.I.C.

J. M. Ragg, B.SC.
J. C. C. Romans, B.SC.

The Soil Survey is concerned with the systematic study and mapping of the soils of Great Britain. The total area mapped since 1946 is now more than 12,000 square miles.

On the 31st March, 1959, the number of scientific and experimental staff was twenty-four in England and Wales and fourteen in Scotland.

CURRENT WORK

About 752 sq. miles of country have been mapped during the year in the counties of Bedford, Glamorgan, Hertford, Kent, Somerset, York, Aberdeen, Ayr, E. Lothian, Perth, Ross and Stirling; soil maps were published for Anglesey (with memoir), Pwllheli and Elgin. Several memoirs and maps are in course of preparation for other areas. Special surveys included experimental farms and sites, the Isle of Rhum, areas of importance in town planning, glass sand winning and forestry. Members of the Pool of Colonial Surveyors have continued their work in Hong Kong, Swaziland, British Guiana and Sierra Leone, and a start has been made in Dominica, B.W.I.

Soil Maps and explanatory memoirs to accompany them are published and an Annual Report on the work of the Survey is issued by the Soil Survey Research Board.

A.R.C. UNIT OF SOIL PHYSICS

School of Agriculture, University of Cambridge

Director: E. C. CHILDS, SC.D., Ph.D.

Senior Scientific Officer: A. N. Ede, M.A., M.Sc., A.M.I.B.A.E.

The main work during the year has been a continuation of that described last year. In the study of the flow net in drained land the combined effect of a capillary fringe and an impermeable layer at a specified depth has been studied by programming the problem for treatment by electronic computer (Edsac II). A new analysis of the static equilibrium of water in porous material has been begun in collaboration with the University of Wisconsin, following a visit to the U.S.A. by the Director in the summer of 1958.

The study of the control of a water table by parallel drains has been extended to take into account the presence of highly permeable strata at specified depths, using the method of electric analogues.

Further theoretical and experimental work has been directed to elucidating the development of a moisture profile due to the draining of an initially saturated soil column to a stationary water table. This has relevance ultimately to the location of a falling water table in drained land following cessation of rainfall.

Field work continued, with the recording of rainfall, ground-water level and drain efflux rate at selected drained sites. Drain activity was widespread only in December and January. Evidence has been obtained as to the relationship between the instantaneous water-table height and flux, but permeability needs to be more intensively studied before this relationship can be checked with theory. It has also been shown that, as expected, the average water table height during a sufficiently long period (of the order of a week) is related to the average net rainfall rate in the same way as the momentary water table height is related to the momentary water table flux. Development of instruments is being continued for reducing possible error of measurement of height of a fluctuating water table.

On 31st March, 1959, the scientific and experimental staff of the Unit numbered three.

PLANT BREEDING

PLANT BREEDING INSTITUTE

Maris Lane, Trumpington, Cambridge

Director: G. D. H. BELL, B.Sc., Ph.D.

CEREALS (WHEAT, BARLEY, OATS)

G. D. H. Bell, B.Sc., Ph.D.

F. G. H. Lupton, M.A.

R. N. H. Whitehouse, M.A.

LEGUMINOUS FORAGE CROPS AND GRASSES

J. L. Fyfe, M.Sc.

H. H. Rogers, B.Sc., Dip.Ag.sci.

PATHOLOGY

R. C. F. Macer, M.A., Ph.D.

MUTATIONS

A. D. McKelvie, B.Sc., Dip.Ag.sci., D.T.A.

BIOCHEMISTRY

A. R. H. Trim, B.A., Ph.D.

POTATOES AND BRASSICAS

H. W. Howard, B.A., Ph.D.

K. F. Thompson, M.A.

SUGAR BEET

G. K. G. Campbell, B.Sc., A.I.C.T.A.

G. E. Russell, M.A., Dip.Ag.sci.

CYTOGENETICS

R. Riley, B.Sc., Ph.D.

Secretary: F. B. Hatfield, B.Sc., D.P.A.

The work of the Institute includes research of a fundamental and applied nature for the improvement of crop plants. These researches in plant breeding have as their objective the production of better varieties with special reference to the agriculture of the intensively farmed and drier areas of England, and the crops being studied are wheat, barley, oats, potatoes, sugar beet, marrow stem kale and thousand head kale, field beans and peas, lucerne, red clover, and the three rotational grasses, cocksfoot, timothy and tall fescue. The breeding work includes methods of improving such characters as yield, quality, disease and pest resistance, winter-hardiness and drought resistance, and special attention is paid to devising better breeding techniques and methods of selection. Fundamental studies are in progress in genetics, cytology, biochemistry, physiology, mycology, virology, statistics and field experimentation, as well as on the possibilities of developing more efficient methods of utilising artificially induced mutations for plant breeding.

On 31st March, 1959, the scientific and experimental staff of the Institute numbered twenty-five.

CURRENT WORK

Intensive efforts are being made to devise the most effective means of speeding up the breeding programmes in the three cereals, while at the same time utilising more comprehensive, more detailed and more accurate methods and techniques. It is imperative to widen the scope of the breeding work by introducing the best of the ever increasing amount of genetic variability available as the result of other breeders' extensive activities. Consequently experiments are being conducted, based on the most recent studies in biometrical genetics, to try to find a sound system of cross prediction, or of rapid evaluation, for the handling of large numbers of individual hybridisations. This work is being done in conjunction with a study of the means of increasing the number of hybrid generations a year,

and of more rapid and efficient methods of selection for such characters as yield, grain quality and disease resistance.

Breeding for resistance to the more important fungal diseases of wheat, barley and oats has been intensified and new methods for the testing of resistance to these diseases in the field have been developed and are being used in the breeding programmes. At the same time it has been possible, with the provision of a specially designed pathology glasshouse, to embark on a considerably more detailed and effective study of the pathogens, including the evaluation of race problems, new sources of resistance, the genetics of resistance, and the synthesis of highly resistant forms for breeding purposes. That it is essential to improve the standard of disease resistance in the three cereals is well demonstrated by the field trials of the Institute's mildew resistant barleys in various parts of the country, which have shown the great value in terms of improved yield of resistance to this disease.

Apart from the improvement in spring barley by means of increased resistance to mildew, there is promise of considerable improvement in winter barley as shown by small scale yield trials. In winter wheat some advance has been made in combining high yield with good bread making quality of the grain, while the culmination of a section of the winter oat breeding programme has been the production of two hybrids which are being multiplied as rapidly as possible for distribution to farmers.

Another practical result of the breeding work may be seen in sugar beet as the Institute has produced a variety which is being grown for the first time by farmers in 1959. This variety, named Cambro, is extremely resistant to bolting, and is consequently suited to early sowing. Work is in progress on the improvement of this stock, and there is already promise of being able to increase its yield. Efforts are being made also to synthesise a variety of good field performance with single-germ seed. From the point of view of breeding technique, the exploitation of polyploidy and of male-sterility are the most important aspects in the sugar beet programme, but at this moment these problems are second in importance to that of developing a commercial variety tolerant to the virus yellows disease. This work continues to yield good results in terms of improving tolerance to the disease in the breeding material, while the co-operative work being conducted with the Biochemistry Section on the pure virology is proving to be of great significance when considered in terms of plant breeding, and of the Biochemistry Section's own work on plant nucleic acids. The whole subject is proving of considerable complexity because of the incidence of strains in the virus which have been found by field surveys conducted by the Institute.

The problem of controlling late blight in potatoes by breeding resistant varieties continues to occupy the attention of the breeders, and new material possessing major genes for resistance to the disease has been sent forward for trial. Efforts are now being made, however, to exploit the so-called field resistance available among commercial varieties, while new importance is being attached to resistance in the tubers. Progress has been made in the breeding of varieties resistant to the common biotype of potato root eelworm, but the discovery of a biotype of this eelworm which can attack potatoes which are resistant to the common biotype, has made it necessary to reconsider the programme and try to exploit other sources of resistance.

Work has continued on a separate potato programme based on breeding for all-round improvement in field and consumer characters.

The investigations on marrow stem kale have given further information on the possibilities of producing improved varieties for specific uses by the farmer, and selection has been directed primarily towards two main types—a short and a medium height variety. Field and edibility trials have been conducted on selected breeding material, and the first steps have been taken in synthesising hybrid stocks based on the maximum exploitation of hybrid vigour. Efforts to exploit a similar breeding system based on inbreeding and subsequent hybrid vigour manifestation through controlled hybridisation are being made in field beans. In the case of beans, however, the occurrence of male-sterility is being used to ensure hybridity, while in kale, the basis is genetically controlled self-incompatibility which compels cross fertilisation.

Breeding experiments with forage and herbage plants have been much concerned with breeding techniques and methods of field assessment. In lucerne, trials were conducted with synthetics and with polycross progenies, and large numbers of pollinations involving inbreeding and controlled hybridisation were made in the glasshouse. The problems of breeding for resistance to *Verticillium* wilt in lucerne, and to stem rot resistance and stem eelworm resistance in red clover have received further attention. Small-scale field trials with cocksfoot and perennial rye grass have been concerned primarily with measuring the potentialities of breeding material, while collections of new indigenous forms of cocksfoot have been made. Further selections have been made in cocksfoot as well as in timothy and tall fescue, and new material has been obtained through the Food and Agriculture Organisation. A special study is being made of out-of-season production.

Progress in the researches on the cytogenetics of the Triticinae has promised to provide valuable information for developing new techniques in wheat breeding. This has resulted from a better knowledge being obtained on the nature of polyploidy in wheat, as well as on the mechanism of control over chromosome pairing at meiosis in polyploid wheats. The synthesis of alien chromosome addition lines and substitution lines in wheat, using rye and species of *Aegilops* has continued, and irradiation techniques have been employed for transferring parts of rye chromosomes onto wheat chromosomes. For further genetic and breeding studies, a monosomic series is being built up in one wheat variety, and a series of crosses involving Institute amphidiploids and wheat varieties has been intensively selected.

The biochemical study of nucleic acids has been concentrated on their analysis as obtained from sugar beet leaves, on the content of these acids in healthy leaves and leaves infected with virus yellows, and on the fractionation of polynucleotide mixtures. Improved preparations of the virus which causes yellows in sugar beet are making it possible to engage in more critical studies of the virus itself. Apart from routine chemical analysis of breeding material in several crops, the chemical laboratory has concentrated attention on the assessment of quality in malting barley.

WELSH PLANT BREEDING STATION

Plas Gogerddan, Aberystwyth

Director: Professor P. T. THOMAS, B.Sc., Ph.D.

Deputy Director: Gwilym Evans, O.B.E., M.Sc.

GRASS BREEDING

A. R. Beddows, M.Sc., F.L.S.
Martin Borrill, B.Sc., Ph.D.
E. L. Breese, B.Sc., Ph.D.

PLANT GENETICS AND PHYSIOLOGY

J. P. Cooper, B.Sc., Ph.D.

HERBAGE LEGUME BREEDING

W. Ellis Davies, B.Sc.
Alice M. Evans, B.Sc., Ph.D.

CEREAL, BEANS AND BRASSICAE BREEDING

D. J. Griffiths, M.Sc., Ph.D.

GRASSLAND AGRONOMY

Ll. Iorwerth Jones, B.Sc.
W. E. J. Milton, M.Sc., N.D.A.
D. G. Miles, B.Sc.
Ieuan Davies, M.Sc.
Arthur Troughton, M.Sc., Ph.D.

SEED MULTIPLICATION

Gwilym Evans, O.B.E., M.Sc.
H. M. Roberts, B.Sc.

CYTOLOGY

Keith Jones, B.Sc., Ph.D.

PLANT PATHOLOGY

A. J. H. Carr, B.Sc., Ph.D.

CHEMISTRY

G. ap Griffith, B.Sc., Ph.D.

SCIENTIFIC LIAISON OFFICER

Ll. Phillips, B.Sc.

Secretary: J. O. Parry-Williams, M.B.E.

The Station is concerned with fundamental and applied research associated with the production of improved varieties of grasses, legumes, cereals and forage *Brassicæ* crops, having particular regard to the climatic conditions of the west.

On the 31st March, 1959, the scientific and experimental staff of the Station numbered forty-two.

CURRENT WORK

Grass Breeding. Investigations are continuing into the genetical assessment of parents in perennial ryegrass, and selected material of four generations of experimental varieties is under study for yield and other characters.

Intergeneric crosses between *Lolium* and *Festuca* show that from the agricultural point of view hybrids with *L. multiflorum* (Italian ryegrass) appear to be potentially more valuable than those with *Lolium perenne* (perennial ryegrass).

The potential varieties of winter-fodgage perennial ryegrass, early-fodder cocksfoot and hay-type timothy are proving valuable for the conditions for which they were bred, and after further agronomic assessment it is hoped to multiply them for seed.

Plant Genetics and Physiology. The study of heritability and response to selection of production characters in ryegrass has been extended to leaf area and rate of leaf appearance. Much additive genetic variation exists within varieties and most plants are highly heterozygous for genes controlling these characters. Rapid response to selection occurs, but selection for rapid leaf appearance leads to smaller leaves, and vice versa.

The effects of these differences on the relative growth rate and on dry matter production are under investigation.

The selection and testing of non-flowering material of ryegrass is being actively pursued, and vigorous non-flowering plants have been obtained in the third generation of selection from S.23. Vegetative perennial ryegrass is capable of continued tillering and steady yields throughout the first growing season if adequate nitrogen is given. Soluble carbohydrates, particularly fructosan, were inversely related to nitrogen supply and were present at rather low levels.

A simulated sward technique for comparing populations and families under controlled competition and defoliation has been developed, and is being used to select and progeny-test parents for particular curves of seasonal production, and also to assess the effect on dry matter production of selection for leaf area and rate of leaf appearance.

Herbage Legume Breeding. Progress was made in the production of a large-leaved variety of white clover, in polyploid red and white clovers, and in the breeding of lucerne.

The yield of spaced plant progenies of white clover was not always correlated with that of the same progenies in swards with ryegrass. In lucerne a plant spacing of 3" $\times$ 3" was the nearest approach to plots sown broadcast.

At high elevations there is differential winter killing between different genotypes of legumes, which indicates the importance of breeding for winter hardiness for upland conditions.

There was a marked increase in the frequency of plants infected with clover phyllody virus and red leaf during the summer of 1958.

Cereal, Beans and Brassicae Breeding. Substantial increases in productivity can be obtained through the elimination of diseases and pests in the cereal crops. Two oat selections, the stem eelworm resistant Winter Selection W271 and the spring type 4757/18/2/19, completed their three years in trials with the National Institute of Agricultural Botany in 1958, and have been officially recommended for distribution. Selection 4757/18/2/19 represents the first variety in which resistance to the three diseases, mildew, crown rust and stem eelworm, have been successfully incorporated into a single form adapted to British agriculture.

In field beans the problem of self-fertility was investigated and attempts made to separate the genetical and environmental factors involved. Progress was made in the programme of inbreeding and evaluating different types of synthetic varieties developed through recurrent selection.

Improvements in yield, winter hardiness and leaf-retaining properties were sought in the kales and rapes through hybridisation and re-selection, and progress was made in the development of an adapted variety of rape resistant to clubroot disease.

Seed Production. Further studies on the effect of plant population on seed production in grasses have brought out the importance of optimum densities, which are found to differ according to genus and species.

Investigations on the management of grass seed crops indicate that season and age of stand will determine the appropriate treatment to use for maximum yield of seed.

Considerable attention is being given to the correct time for harvesting grass seed crops, and results have shown, for example, that the three varieties of timothy have a different optimum date for harvesting.

Studies on longevity of seed indicate that viability is favoured in seeds which are kept below the water level of the soil.

Grassland Agronomy. A method of evaluating new varieties of grasses under sward conditions is being developed whereby the fertility due to animal excreta is taken into consideration. In this way information is obtained not only on productivity but also on changes in the botanical composition of the sward.

For continued production of leaf there is a critical phase for defoliation in relation to the development of the flowering head, and a precise knowledge of this in different varieties will indicate to the farmer how to obtain the maximum yield of nutritious herbage.

The problem of competition between a cereal nurse crop and the undersown grass/clover mixture has received attention. Under certain conditions there is a marked reduction both in the yield of the cereal and in the take of grass and clover.

Chemistry. Increasing attention is being given to the nutritive value of herbage, both in relation to management and to the breeding of new varieties. The discovery at this Station of the accumulation under certain conditions of mineral nitrates has a direct bearing on animal well-being. Furthermore, important differences between varieties are being found in respect of such constituents as N/A fibre, carbohydrate and nitrogen fractions.

A fuller description of the Station's work is given in its Report for 1956-58.

SCOTTISH PLANT BREEDING STATION

Pentlandfield, Roslin, Midlothian

Director: J. W. GREGOR, D.SC., Ph.D., F.R.S.E.

POTATO BREEDING

W. Black, D.Sc., Ph.D., F.R.S.E.

HERBAGE PLANTS AND GENECOLOGY

Patricia J. Watson, M.A., Ph.D.

VIRUS DISEASES OF POTATO

G. Cockerham, B.Sc., Ph.D.

BRASSICA BREEDING

V. E. M. Davey, B.Sc., Ph.D.

CEREALS

D. Cameron, B.Sc.

BRASSICA CYTOGENETICS

I. H. McNaughton, B.A.

Secretary: R. J. L. Gallie

The aims of the Station, established in 1920, are: (a) to conduct investigations calculated to yield information of scientific interest bearing upon the general problems of crop improvement; and (b) to produce new and improved varieties of direct value to agriculture.

On 31st March, 1959, the scientific and experimental staff of the Station numbered seventeen.

CURRENT WORK

Oats. In 1953 with the help of the North and West Colleges of Agriculture two regional selection centres were established one in Argyll and the other in Inverness-shire, and these centres together with Pentlandfield provide three contrasting environments in which to make selections from unfixed hybrid material produced at Pentlandfield. Sufficient time has now elapsed to permit of a preliminary assessment of the merit of making the selections within the actual environmental regions for which the breeding programme is intended to cater.

A number of related lines, derived from the same crosses and selected at the three centres on the basis of grain yield, were tested in 1958. At Pentlandfield the lines selected there were generally superior to those selected in Argyll; but the converse was found in a parallel trial in Argyll, as the lines which excelled at Pentlandfield were not the best yielders in Argyll.

Work on the resistance to stem eelworm has greatly expanded, and a number of resistant lines have been obtained.

Herbage Plants and Genecology. The investigation of the extent and distribution of variation within hill land species has been continued and has involved a genecological study of the structural details of the plant communities which make up hill grazings. The primary need at the moment is to acquire basic information about the significance of ecotypic and fortuitous variation in studies concerned with community dynamics. The analysis of a genecological trial comprising a number of taxa derived from 226 upland sites is in progress. The necessary preparatory separation of chromosome races has been completed. In the *Festuca ovina* complex, for example, samples from 194 habitat populations in South-East Scotland were of three types: 37 samples being diploid, 123 tetraploid and 34 mixed. Three types have also been found in the *F. rubra* group—hexaploid, heptaploid and octoploid.

Work on virus diseases of grasses has been started. A virus was transferred from stunted *Festuca ovina* plants to oat seedlings in which it caused severe stunting and leaf malformation. A virus less damaging to oats was found in *F. ovina* plants of normal appearance and may have been present also in the stunted plants, though this has not been demonstrated.

Potatoes. Efforts are being concentrated on breeding for field resistance to potato blight, though hypersensitivity has not been ignored. The existence of a fifth R gene in *Solanum demissum* was confirmed, as was also the existence of a race of blight capable of overcoming it, a finding which emphasises that hypersensitivity is an unreliable form of protection against the disease.

Genetical studies on various characters associated with resistance to viruses were continued. In progenies derived from *Solanum chacoense* resistance to virus Y is manifested in two forms—a null reaction and a necrotic hypersensitive reaction. Attempts to utilise the resistance of *S. chacoense* in general breeding have been made by means of the diploid-hexaploid cross *S. chacoense* $\times$ *S. demissum*, and also by using colchicine-induced tetraploid *S. chacoense* in crosses with *S. tuberosum*.

Sources of resistance to the two strains of potato root eelworm occurring in Britain have been found.

For some years past the Station has been sending samples of potato seedlings to various parts of the world for trial. Several seedlings have given good results in Kenya, and five of them, though unsuited to Scottish conditions, are now in commercial production in Kenya. At the request of the Department of Agriculture in Kenya these five cultivars have been named. In addition another cultivar suitable for cultivation in Britain has been registered by the Department of Agriculture for Scotland and named Pentland Crown.

Brassica crops. The examination of hybrids between thousand-head kale and heading broccoli, sprouting broccoli, kohlrabi and cabbage has been continued. It is clear that the economic suitability or otherwise of the hybrid derivatives depends very largely on the choice of the kale parent.

Plants of the *Brassica campestris* group (which includes *B. japonica*) have been crossed amongst themselves and also with *B. oleracea* and *B. napus*. One hybrid of the cross *B. japonica* $\times$ *B. napus* was morphologically distinct from the others and proved to be a spontaneously doubled form with 58 chromosomes. Tetraploids of *B. oleracea*, *B. campestris* and *B. hirta* have been produced.

Several techniques for the production of tetraploids were tried. The best results were obtained by spacing seedlings in boxes and applying colchicine to the stem apices at the cotyledon stage. Chromosome counts showed that 30–40 per cent. of cuttings taken from treated plants were doubled.

A fuller account of the work is given in the Station's Annual Report.

A.R.C. UNIT OF BIOMETRICAL GENETICS

Department of Genetics, University of Birmingham, Edgbaston, Birmingham

Honorary Director: Professor K. MATHER, C.B.E., D.Sc., Ph.D., F.R.S.
(Professor of Genetics, University of Birmingham)

Senior Scientific Officer: J. L. Jinks, B.Sc., Ph.D.

The unit was formed on 1st October, 1950. It is attached to the Department of Genetics in the University of Birmingham and the Professor of Genetics is its Honorary Director. On 31st March, 1959, the scientific and experimental staff numbered six.

CURRENT WORK

The principles underlying the inheritance of continuous variation are now hardly in dispute, and attention has come to be concentrated more and more on the development of the necessary mathematical theory and on the design and analysis of experiments to provide estimates of the genetical and other parameters that this theory requires. Genetics, and especially biometrical genetics, is approaching the position familiar in physics and chemistry where a distinction of specialisms is recognised between the theoretical or mathematical and the experimental. This is a position with

obvious dangers, and the continued combination of theoretical and experimental investigations within single units is essential if development is to proceed in any reasonably balanced fashion.

The general mathematic treatment has now provided us with sets of tests which will distinguish between the consequences of mechanical linkage of genes in inheritance and their physiological interaction in development as well as giving us a comprehensive picture of the interplay of linkage and interaction in the descendants of single crosses between true-breeding lines. It is also pointing the way to means of estimating the effective number of units of genetical segregation in a cross and of evaluating the magnitude of effect produced by these units. Difficulties can, however, be confidently expected in applying these methods to experimental data and these are being explored by appropriate experimentation.

Earlier investigations have shown that chromosome behaviour provides a sensitive indicator of genetic divergence between individuals and of differences arising within individuals by the differentiation of cells and tissues. These potentialities of chromosome studies have been exploited in a number of ways. They have brought to light gradients arising from the processes of differentiation within anthers of rye plants. They have shown the absence of serious barriers to the exchange of genes between perennial and italian rye grasses, and here indeed chromosome behaviour has proved more sensitive than morphological characters in detecting divergence. Finally they have facilitated study of the genetic relations between wild populations of campion.

Studies of thirty-four isolates of the potato-blight fungus (*Phytophthora infestans*) collected from nineteen varieties of potato have revealed wide variation in morphological characters and, more important, in the speeds with which they attack potato leaves and in their rates of growth and depths of penetration of tubers. Most of this variation is related to the so-called field resistance of potatoes to blight and has nothing to do with genes conferring the ability to attack potato varieties bred in the vain attempt to achieve full immunity to the fungus. Certain differences in the abilities of the fungal isolates to attack potatoes have been related to differences among the potato varieties from which the isolates were first obtained. It seems that this relation is likely to spring from natural selection of the fungus by the potato varieties, rather than from somatic adaptation of the fungus to its host; but evidence capable of deciding this question must await further investigations.

Experiments with the fruit fly, *Drosophila*, have revealed differences in the ways in which certain of the flies' characters are controlled genetically. These differences in genetical architecture can be related to the different actions of natural selection on the characters. The same principles must apply in domestic plants and animals so that the past action of natural, and artificial, selection will set limits to the ways in which future selection can achieve improvements, at least in the short term. In other words, the possibilities open to artificial selection of the future are determined in a broad sense by the way natural selection has acted in the past.

PLANT PHYSIOLOGY

UNIT OF PLANT PHYSIOLOGY

Beit Building, Imperial College of Science and Technology,
London, S.W.7

Director: Professor H. K. PORTER, D.SC., A.R.I.C., D.I.C., F.R.S.

Senior Scientific Staff:

Miss O. N. Purvis, D.SC., PH.D.

C. L. Mer, B.SC., PH.D., A.R.C.S.

The Unit was established on 1st January, 1959, and is continuing those aspects of the work of the former Research Institute of Plant Physiology which were carried on in the laboratories of the Imperial College and at Chelsea Physic Garden.

On 31st March, 1959, the scientific and experimental staff of the Unit numbered seven.

Carbohydrate Metabolism. The pathway of starch dissolution in tobacco leaf tissue in attached leaves has now been investigated. Only 45 per cent. of the CO_2 of respiration was found to derive from starch and sugar, as compared with 60 per cent. in detached leaves, although starch breakdown was more rapid in the former case. In attached leaves starch degradation products appear to be more readily translocated out of the leaf than used as substrate for respiration. The nature of the non-carbohydrate source of respiratory carbon is under investigation. In attached leaves in light there is a continuous "turn over" of starch under conditions in which the amount either remains constant or increases. It is likely that this exchange is restricted to the outer layers of the starch grains. There is little movement across the leaf lamina of sugars newly formed by assimilation of $^{14}\text{CO}_2$, and little radioactivity can be detected in the veins or midrib, although rapid translocation is proceeding. Sugar thus appears to pass from its site of formation directly into the conducting channels then move out of the leaf very fast.

In the studies in progress on wheat seedlings emphasis has been given to the problem of the origin and metabolism of the soluble nucleotides. It has first been necessary to develop quantitative methods for their separation. No free nucleotides were detected in endosperm tissue, although during germination at 25°C . a rapid increase in concentration occurred in the embryo. The bases contained a high proportion of guanine relative to cytosine, and uridine diphosphate glucose was always present.

Growth of oat seedlings. Both CO_2 and ethanol have been shown to stimulate the extension of the oat mesocotyl in the dark. Using radioactive ethanol its effect has been found to be due to oxidation to CO_2 . Outflow of material from the endosperm is promoted by light, but reduced in the dark by both CO_2 and ethanol. No marked change in sugar level in the endosperm accompanied these effects. In the leaves which contain 86 per cent. of the seedling sucrose there was increase in sucrose level and decrease in reducing sugar following the CO_2 and ethanol treatments. However, redistribution of carbohydrate does not appear to be an important aspect of the stimulating effect of CO_2 on mesocotyle extension.

Further examination of possible interactions between auxin and metal ions in relation to the light sensitivity of oat seedlings has revealed no alterations in sensitivity when glycine with manganese or cobalt was used, nor do these ions promote mesocotyle extension as does copper glycine.

Vernalisation Studies. A number of outstanding points in regard to interactions between vernalisation and other factors has been examined. It is now established that reduction in response to vernalisation in winter rye due to previously applied high temperature is similar in whole grains and embryos.

Spring rye was shown to be unaffected by vernalisation, whether grown subsequently in long or short days. A single cycle of continuous light induced exsertion of ears and pollen in Spring rye plants 28 days old when the plants were kept in short days, and longer exposures to continuous light resulted in proportionate acceleration of flowering. A single continuous light cycle (32 hr.) was ineffective with plants 17 days old or less.

Inhibition of flowering in Spring rye kept in short days appears to be, at least in part, due to failure of stem extension. An attempt to overcome this failure has been made by applications of gibberellic acid. The expected effect on stem extension occurred, but the treated plants had marked structure abnormalities in the apices. When plants were kept in long days, gibberellic acid had no effect. With vernalised winter rye, gibberellic acid again had no effect on flowering, despite a notable increase in stem length and a reduction of tillering. In unvernalsed winter rye early treatment with gibberellic acid (3rd leaf) resulted in late earing with many abnormalities, while with late treatment (9th leaf) normal spikes were formed.

A.R.C. UNIT OF PLANT MORPHOGENESIS AND NUTRITION

Rothamsted Experimental Station, Harpenden, Herts.

Director: F. J. Richards, D.Sc., F.R.S.

Principal Scientific Officer: W. W. Schwabe, D.Sc., Ph.D.

In December, 1958, the Research Institute of Plant Physiology came to its end. The present Unit was established to continue the work of that section of the old Institute which was situated at Rothamsted Experimental Station. Its work is broadly physiological, the investigation of metabolic and developmental effects of deficiencies of the major nutrient elements, and studies in other developmental processes of a morphogenetic nature: flowering and photoperiodic behaviour, and interrelationships between growth and form at the stem apex.

On 31st March, 1959 the scientific and experimental staff of the Unit numbered four.

CURRENT WORK

During the year, the "critical daylength" for photoperiodic response was studied in both long-day and short-day species. In *Kalanchoe blossfeldiana* the critical daylength was shown to increase appreciably during

the period of induction, i.e. daylengths of $12\frac{1}{2}$ –13 hours, which do not induce flowering in plants exposed previously only to longer days, nevertheless increase substantially the amount of flowering in plants already partially induced by a few short days. The effects of daylength on growth and dormancy of the liverwort *Lunularia* have been analysed further. The stoppage of growth in long days is accompanied by dissolution of the contents of the marginal cells of the thallus, and by accumulations of starch, sucrose, glutamine and arginine. These changes confer considerable powers of drought resistance, thus enabling the plant to survive the hot, dry season in its natural environment.

Analysis of the relations which exist in flax between apical size, apical growth rate, and phyllotaxis height, with their modifications under conditions of nutrient deficiency, has been completed, or at least carried as far as seems profitable at present.

The study of the production of putrescine by some potassium-deficient plants has been continued. Attempts to detect decarboxylases of ornithine and arginine in barley macerates have so far proved abortive, while experiments which involve feeding plants with arginine containing radioactive carbon have emphasised the need for defining more closely the conditions under which the amine normally accumulates in potassium-deficient plants. Such factors as light intensity and temperature appear to be involved to an important degree, and further investigations are being made into the interplay of this complex of factors. A preliminary survey has now been made of the occurrence of free mono-, di-, and tri-phosphate nucleotides in leaves from barley grown at different potassium levels. The impetus for this research is the assumption, often made, that deficiency of potassium uncouples phosphorylation from respiration. The analyses, however, have revealed no important changes in the free nucleotide composition due to potassium deficiency. Quantitatively, these results are still rather crude and, with a view to obtaining more critical data during the summer of 1959, further steps have been taken to improve the analytical techniques.

PASTURE

THE GRASSLAND RESEARCH INSTITUTE

Hurley, Maidenhead, Berkshire

Director: William Davies, D.Sc., Hon.D.Sc. (N.Z.)

Deputy Director: T. E. Williams, B.Sc.

LEY AGRONOMY

Head of Department: T. E. Williams, B.Sc.
C. R. Clement, B.Sc., Ph.D.
A. J. Heard, M.Sc.
W. Stiles, M.Sc.

ANIMAL AGRONOMY

Head of Department: F. E. Alder,
D.F.C., M.A., B.Sc.
J. C. Tayler, M.A., Dip.Ag.
D. E. Eyles, M.Sc.

HERBAGE AGRONOMY

Head of Department: J. O. Green, M.Sc.
D. W. Cowling, B.Sc.

BIOCHEMISTRY AND ANIMAL NUTRITION

Head of Department: W. F. Raymond,
M.A., A.R.I.C.
J. M. A. Tilley, B.Sc., D.Phil.
E. C. Jones, B.Sc., F.R.I.C.

Secretary: I. A. Owen

PLANT PHYSIOLOGY

Head of Department: O. R. Jewiss,
B.Sc., Ph.D., A.R.C.S., D.I.C.
R. D. Williams, B.Sc., Ph.D.

GRASS/ANIMAL ECOLOGY

C. R. W. Spedding, M.Sc., Ph.D.
D. D. Kydd, M.A.

BIOMETRICS

C. D. Kemp, B.Sc., Dip.stat.

EXTRA-MURAL STUDIES

H. K. Baker, B.Sc., Ph.D., Dip.Ag.

MICROBIOLOGY

Miss E. Grossbard, Ph.D., D.I.C.

Librarian: E. W. Brennan Jones, M.A.

At 31st March, 1959, the scientific and experimental staff at the Institute numbered fifty-two.

The Grassland Research Institute is primarily concerned with grassland herbage as a diet for the ruminant and with the grass crop as a soil improver. Field experiments play an important part in the work of the Institute, but the research team also includes workers in disciplines other than agronomy. For example the chemistry and bio-chemistry of pasture plants are important in evaluating herbages of different sorts, grown under a variety of treatments, and add to the understanding of the behaviour of farm animals when fed on these contrasting diets. Similarly plant and animal physiology, microbiology, soil chemistry, biometrics and animal parasitology are represented in the programme and each contributes to the better understanding of field assessments.

On 31st March, 1959 the scientific and experimental staff of the Institute numbered fifty-two.

CURRENT WORK

Herbage Agronomy. This department is interested in new plant material and the development of new techniques which might lead to an extension of the effective grazing season. Its studies include exploring management and manuring factors in relation to growth and nutritive values of herbage plants. Techniques designed to improve the correctness of assessment of values applied to different herbages have already proved fruitful. A study of the part played by nitrogen in determination of pasture growth is

relevant to the role of the legume constituent of grassland in relation to herbage production and soil chemistry.

Ley Agronomy. The influence of contrasting grassland herbages upon yield of subsequent arable crops can be very marked. Long duration leys when ploughed up and followed by wheat provide a wide range of grain yields (at Hurley the yields are within the range 28–55 cwts. grain per acre). These differences are closely correlated with the quantity of mineralised nitrogen in the soil. Changes attributable to the ley also occur in the physical condition of the soil and in its content of organic matter. Differential incidence of pests consequent upon leys of different types has opened interesting lines of investigation. Certain stem-boring larvae (e.g. *Oscinella* spp.) are more common after ryegrass than after cocksfoot leys and have had an important influence upon wheat yields. Detailed studies on grassland irrigation have been continued and are contributing to knowledge of the seasonal and the overall growth of pasture plants.

Animal Agronomy. The work of this department integrates that of others on animal production. Much of it involves carrying animals at pasture for the full twelve months of the year. Where necessary supplementary feed is on offer, usually silage and hay. Comparative trials in progress are designed to evaluate different herbages through the beef animal and with sheep. Detailed records are made of animal performance (thrift, seasonal live-weight gain, weight of carcass at slaughter and meat quality etc.). Studies are also being made of the rearing of beef calves on an all-grass diet. These suggest interesting new techniques of calf-rearing and have also led to a study of disease control (e.g. husk) by appropriate pasture management.

The food intake of grazing animals has been closely studied in the field and related to herbage type and to apparent digestibility.

Grass/Animal Ecology. The ecology of pasture growth and development is studied in the context of animal thrift and animal physiology. Up to date, the emphasis has been on fat lamb production (used as a measure of pasture output) with special attention to “worm” burden in the immature animal. For this purpose, lambs may be suckled on their mothers or they may be reared “artificially” (off their mothers but chiefly on pasture). Observations are made of the influence of “worm burden” on nutrition, lambs of known but contrasting “burden” being fed on different swards and compared for their thrift and value at slaughter. The influence of “worm burden” upon reproduction in the breeding flock is also being studied.

Biochemistry and Animal Nutrition. The nutritive values of various herbages are under critical examination. It is now established that herbage species differ widely in their digestibility at a given date and also at a given stage of physiological growth. The probable usefulness of a given herbage to the ruminant animal can therefore be predicted. Marked differences are found between herbages in their contents of nitrogen, soluble sugars, cellulose, hemi-cellulose and other constituents. In addition to basic research into the biochemistry of plant materials, the department also provides an analytical service for the Institute as a whole.

Plant Physiology. Growth and development of grasses and clovers are studied on the whole plant (tops and roots) and in response to contrasting

environmental treatments. Some of the work in progress has an intimate bearing upon the development of seed in relation to treatment and may suggest new methods leading to enhanced seed yields.

Microbiology. The basic subject of study is the manner of decomposition of plant residues in the soil, the work being closely related to much of that in Ley Agronomy. Radio-active materials and autoradiography are employed as tools to measure the spread of certain micro-organisms in the soil, and in an attempt to understand better the processes by which nutrients are released.

Biometrics. This section offers a computing service and also gives statistical advice to other sections of the Institute especially in the design of field and laboratory experiments. It maintains therefore the closest possible association with research projects throughout the Institute. It also conducts basic research into biometric methods, using data from the many programmes under way. The aim is thereby to develop new biometric techniques to improve both design of pasture/animal experiments and the reproducibility of experimental results.

Extra Mural Studies. Field experiments are conducted under a wide range of conditions all over the country. These experiments are closely connected with those at the Institute and afford additional information of value to the headquarters research staff. At the same time they indicate how far results obtained at Hurley may be applicable elsewhere. Special problems associated with "difficult" soils, e.g. Bagshot sands, also form a part of this work.

The Annual Report of the Institute is published as "Experiments in Progress". This gives a detailed account of the research work and of the range of projects under study.

HORTICULTURE, GLASSHOUSE CROPS AND FRUIT

JOHN INNES HORTICULTURAL INSTITUTION

Bayfordbury, Hertford, Herts.

Director: K. S. Dodds, D.Sc., Ph.D.

GENETICS

Head of Department: Vacant
P. R. Day, B.Sc., Ph.D.

PLANT BREEDING

Head of Department: Watkin Williams, M.Sc.
G. J. Dowrick, B.Sc., Ph.D.
H. Williams, B.Sc.

PLANT CELL BIOLOGY

Head of Department: Vacant
L. F. La Cour, M.B.E.
J. W. C. Crawley, B.Sc.
J. McLeish, B.Sc., Ph.D.
N. Sunderland, B.Sc., Ph.D.

POTATO GENETICS

Head of Department: K. S. Dodds,
D.Sc., Ph.D.
R. K. McKee, M.A., Ph.D., A.I.C.T.A.
J. B. Harborne, B.Sc., Ph.D.
G. E. Marks, B.Sc.

PHYSIOLOGY AND PLANT CULTURE

Head of Department: W. J. C. Lawrence,
O.B.E., V.M.H.
G. Hussey, B.Sc., Ph.D., A.R.C.S., D.I.C.
R. M. Whittle, B.Sc., Ph.D.

Secretary: G. R. Davies

The John Innes Horticultural Institution is concerned primarily with the investigation of the principles of inheritance in plants and their

application in the improvement of agricultural and horticultural crops. A study is being made also of some physiological factors that control the growth and culture of plants.

On 31st March, 1959, the scientific and experimental staff of the Institution numbered forty-one.

CURRENT WORK

The following are some items of interest from the year's investigations:—

Genetics. Studies of the structure of the mating type loci of the tetrapolar basidiomycete *Coprinus lagopus*, carried out with the aid of linked markers, have shown that the *A* locus is made up of at least two subunits which may recombine to give non-parental *A* factors. Examination of heterocaryons between various strains with no, one or both matings factors in common suggests that the *A* locus controls synchronous nuclear division and clamp formation and the *B* locus controls the migration of nuclei in matings. Work is proceeding on the analysis of some spontaneous mutants affecting the two mating loci, which give partial or complete self fertility.

The smut fungus *Ustilago maydis* possesses certain qualities which make it technically suitable for the investigation of genetic problems which require the classification of large numbers of progeny. Heterozygous diploids have been obtained from biochemically deficient haploid strains, and rare spontaneous mitotic recombination has been demonstrated. The rate of this recombination is considerably increased by treatment of diploid cells with ultra-violet light. It is hoped that an investigation of the quantitative effects of this and other mutagenic agents may throw some light on the mechanism of recombination.

Plant Cell Biology. Using the radio-active compound ^3H -thymidine, which is incorporated specifically into DNA, and the stripping film technique, evidence has been obtained which suggests that colchicine treatment applied before and during the synthesis of DNA at mitosis influences the distribution of the acid to sister chromatids at metaphase.

The dry mass of entire cells and isolated nuclei of *Allium cepa* is being determined by interference microscopy. Ultimately these measurements should provide basic values to which the quantities of individual substances, determined by cytochemical techniques, can be related.

In work on the metabolic changes that occur during the development of shoot meristems, particular attention is being given to the period when leaf initiation ceases and the initiation of floral primordia commences. Rates of cell division, cell expansion and oxygen uptake are being measured and protein and nucleic acid contents are also being determined. The structure of the cells of the shoot apex is being studied in the electron microscope.

Physiology and Plant Culture. The study of rates of differentiation of leaves and flowers in the young tomato is being continued. During the initial vegetative phase, increasing temperature leads to more rapid formation and development of leaf primordia but a slower rate of expansion of the apex. With decreasing temperatures the apex expands more rapidly than at high temperatures and flowers are initiated earlier with fewer leaves

formed. Temperature effects are also being studied on the development of the inflorescence from initiation onwards.

A second growth room unit has now been completed and data on climate and control are steadily being accumulated.

Plant Breeding. Particular attention has been paid during recent years to breeding for resistance to apple scab and apple mildew. The initial stages of this work are nearing completion and a total of 2,745 disease-resistant seedlings are now available for selection. Hybridisation designed to give seedlings to fill varietal gaps in the crop have also been made.

Investigations on the possibility of fixing high levels of character expression in pure breeding lines of the tomato have been completed. From F_2 populations of approximately 3,500 plants from each of two hybrids, twelve selections have satisfied the standards imposed during selection, and five selected lines have given early yields of fruit equal to, or exceeding, these F_1 hybrids. It appears that although F_1 tomato hybrids may in certain circumstances make excellent varieties, their use is not essential for the maximal expression of yield characters.

Potato Genetics. Investigations have been started on aspects of the genetic variability of the fungus *Phytophthora infestans* that are relevant to a study of field resistance as compared to *R* gene resistance. The growth rates on tubers of several isolates of the common race (Race 4) have been found to differ but no rapid adaptation of the fungus to better growth on a given variety has been observed. An antiserum prepared by intravenous injection of zoospores of Race 1,4 into rabbits immobilised zoospores at a dilution of 1 : 1,000. The zoospores of the isolates examined differed little in sensitivity and gave apparently identical precipitation zones. The marked effects of the antiserum on mobility suggest that the component may be associated with the flagella.

The first demonstration of the presence in nature of anthocyanins containing three sugar residues was the discovery of the acylated 3-rhamno-glucosido-5-glucosides in red and blue potato tubers. Further work now shows that both anthocyanins and flavonals containing three sugar residues are of fairly frequent occurrence in nature; for example, they occur in the Solanaceae, Primulaceae, Papaveraceae, Iridaceae and Gesneriaceae.

A more detailed account of the research in progress is given in the Annual Report published by the Institution.

GLASSHOUSE CROPS RESEARCH INSTITUTE

Rustington, Littlehampton, Sussex

Director: F. W. Toovey, O.B.E., B.Sc., A.R.C.S., A.I.C.T.A., M.I.Biol.

PLANT PHYSIOLOGY

Head of Department: E. R. Leonard,
D.Sc., A.R.C.S., M.I.Biol.
A. J. Cooper, B.Sc., Ph.D.,
H. R. B. Hack, B.A.

CROP PROTECTION

Head of Department: W. H. Read,
M.Sc., F.R.I.C.

PLANT PATHOLOGY DIVISION

Head of Division: L. Broadbent,
D.Sc., Ph.D., M.I.Biol.

Secretary: J. Bishop, A.C.I.S.

Nursery Manager: J. M. Evans, N.D.H.

ENTOMOLOGY

Head of Department: N. W. Hussey,
B.Sc., Ph.D.

CHEMISTRY

Head of Department: G. W. Winsor,
B.Sc., Ph.D., A.R.I.C., D.I.C.
J. N. Davies, B.Sc., Ph.D.
P. B. Flegg, B.Sc., A.R.I.C., M.I.Biol.

PLANT BREEDING

L. A. Darby, B.Sc.

MYCOLOGY AND VIROLOGY

Head of Department: P. H. Williams,
B.Sc., M.I.Biol.

Librarian: Miss G. Dunster, B.A.

The Institute was established in 1953 to undertake research bearing on the cultivation of glasshouse crops and mushrooms, and of bulbs, flowers and shrubs grown in the open. The Institute is still being developed, the buildings completed during the year being the special experimental glass-houses and the mushroom research buildings. Other facilities required were in the planning stage.

On 31st March, 1959, the scientific and experimental staff numbered twenty-eight.

CURRENT WORK

Plant Physiology. The long term experiment on the effect of time of year in relation to the age of a tomato plant on the growth of the different organs, undertaken as part of the basic study of tomato growth, was continued, and in collaboration with three other centres, in Scotland, the Midlands and the Channel Islands, was extended to different latitudes. Increased attention is being paid to the problem of uneven ripening in tomato fruit, known commercially as "blotchy ripening", and computation of three years' data recorded during the course of the growth analysis work is being undertaken on the electronic computer at Rothamsted to examine the inter-relation during development and ripening of the different forms of fruit coloration and sunshine and temperature in the glasshouse.

Methods of measuring factors of the glasshouse environment likely to influence growth are being developed further and tested.

Chemistry. Continuing the broad study of the chemical composition of tomato fruit, subjects chosen for investigation during 1958 included the effect of nutritional factors and shading on composition and a comparison of the fruit of different varieties. A study of pectic enzymes has been started as it seems likely that these enzymes are intimately associated with the softening of the tissues which accompanies ripening, and hence knowledge of them should contribute to our understanding of normal and abnormal ripening processes in tomato fruit.

Experiments on various aspects of the nutrition of the tomato, including experiments on liquid feeding, were repeated, and long term fertiliser trials on the tomato and carnation, which aim to study the basic nutritional requirements of these two crops, were started. These experiments and trials are accompanied by extensive analytical work for nutrient uptake studies.

Work on the casing layer in mushroom cultivation has been pursued, and the results of experiments in which soluble salts were added to the casing and/or the compost have shown clearly that fruiting will not take place until the moisture stress at the surface of cultivation is reduced to a sufficiently low level by suitable means. There are important practical implications from this work for the grower, both as regards the preparation of the compost and the treatment of the casing layer.

Crop Protection. Subjects which have received special attention are the control of petal blight (*Itersonilia perplexans*) or "damping" on chrysanthemums, which caused much damage during the year, and the persistence in mushroom composts of insecticides used for the control of mushroom flies. The investigation and trial of fungicides for the control of *Didymella* stem rot of the tomato and mildew on cucumbers has continued, and further work has been done on the red spider mite problem.

Plant Breeding. The programmes for tomato, cucumber and lettuce breeding previously outlined have followed their normal course, and with the tomato, selections from crosses of the "Baby Lea" variety with varieties having superior fruit reached the F_5 generation. Lettuce plants, raised from irradiated seed, showing sectorial changes in leaf colour were selected and a second generation produced. Second generation seed was also obtained from crosses of "Cheshunt 5B" with lighter coloured varieties.

Statistics. A Statistician has been appointed to assist with the design and analysis of experiments and to undertake special statistical investigations in connection with the Institute's research programme.

Plant Pathology. A new division of the research staff has been formed by amalgamating the Departments of Entomology and Plant Pathology. This has been done to strengthen the Institute's work in the broad field of pests and diseases and to enable particular attention to be paid to virus diseases. Dr. L. Broadbent, formerly of Rothamsted Experimental Station, has been appointed as head of the new Division.

The biology of mushroom pests (Cecids, Phorids and Sciarids) has been further studied, and an interesting discovery has been made of an eelworm parasitic on the Phorid *Megaselia halterata* which is a common pest in this country. The life-history of the eelworm is being studied to see whether there is any prospect of developing an economic method of controlling the pest by means of the parasite. With mushroom Cecids a problem of considerable interest and practical importance is the unusual mode of reproduction known as paedogenesis, by which the larvae produce further young larvae within themselves and so continue reproduction indefinitely, with only the occasional appearance of adults. The effect of various factors on paedogenesis are being investigated. Experiments on the control of Cecids with insecticides, and the effect of the latter on cropping have also been carried out.

The influence of temperature and plant nutrition on infection of the tomato with *Didymella* stem rot has been investigated, and further study

made of the antagonism to the fungus *Didymella* by other organisms in the soil. Alternate hosts of the fungus causing cucumber mildew have been sought, and an initial study has been made of the fungus (*Itersonilia perplexans*) causing petal blight ("damping") on chrysanthemums. In the work on carnation wilt diseases attention has been focussed on improving the tests for producing "cultured" cuttings which are now widely used by the industry to ensure disease-free planting material. Mushroom disorders of the type known by such names as "La France" disease, "Brown" disease or "Watery Stipe" have received further attention, and experiments have been carried out to see if they can be transmitted by compost or casing material from affected crops, or by spawn made from mycelium or fruit bodies from such crops. Laboratory studies on the mycelium from infected crops have also been made. The study of yellow moulds in mushroom compost has been resumed.

A fuller account of the Institute's work is given in its Annual Report.

EAST MALLING RESEARCH STATION

East Malling, Maidstone, Kent

Director: F. R. TUBBS, M.Sc., Ph.D., A.R.C.S., D.I.C., F.L.S.

Advisers to Director: T. N. Hoblyn, O.B.E., Dip.Hort.
R. V. Harris, D.Sc., A.R.C.S., D.I.C.

Assistant to Director: H. B. S. Montgomery, B.A., Ph.D., D.I.C.

POMOLOGY

Head of Department: W. S. Rogers,
M.A., Ph.D., D.Sc., Dip. Hort., A.Inst.P.
Miss A. B. Beakbane, B.Sc., Ph.D., N.D.H.
R. M. Fulford, B.Sc.
R. J. Garner, M.Sc., N.D.H., Dip.Hort.
R. L. Knight, O.B.E., Ph.D., D.Sc., A.I.C.T.A.,
Dip.Agric.
Miss I. Modlibowska, Ph.D., Dip.Hort.
Miss B. G. Mosse, Ph.D., Dip.Hort.

PLANT PHYSIOLOGY

Head of Department: H. W. B. Barlow, B.Sc.
C. R. Hancock, B.Sc.
E. S. J. Hatcher, Ph.D.
F. W. M. Llewelyn, B.Sc., A.R.C.S.
D. H. Maggs, B.Sc.

FRUIT NUTRITION

Head of Department: D. W. P. Greenham,
M.A., Ph.D.
Miss A. V. Delap, B.A., B.Sc.
J. E. Goode, B.Sc.

PLANT PATHOLOGY

Head of Department: A. F. Posnette,
M.A., Sc.D., Ph.D., A.I.C.T.A.
Deputy Head: J. E. Crosse, B.Sc., Ph.D.
D. S. Kirkham, Ph.D.
J. T. Legg, B.Sc.
M. H. Moore, M.Sc., Ph.D., Dip.Hort.
P. W. Talboys, Ph.D., D.I.C.

Secretary: R. L. Oxley

PLANT PROTECTIVE CHEMISTRY

Head of Department: A. H. M. Kirby,
M.Sc., Ph.D., F.R.I.C.
M. Allen, B.Sc.
R. P. Tew, B.Sc., F.R.I.C.

STATISTICS

Head of Department: S. C. Pearce,
B.Sc., Ph.D.
G. H. Freeman, M.A., Ph.D., Dip.Hort.
P. Sprent, B.Sc.

BIOCHEMISTRY

Head of Department: A. E. Flood,
M.A., Ph.D.

PLANT ANALYSIS

Head of Department: A. C. Mason,
M.Sc., F.R.I.C.

ENTOMOLOGY

Head of Department: G. H. L. Dicker,
B.Sc., Ph.D., A.R.C.S., F.R.E.S.
Miss E. Collyer, Ph.D.
A. M. Massee, O.B.E., D.Sc.
R. C. Muir, B.Sc.
R. S. Pitcher, Ph.D., Dip.Agric., Dip.Entom.

SCIENTIFIC LIAISON

Head of Department: H. B. S. Montgomery,
B.A., Ph.D., D.I.C.

Librarian: S. R. Ball, B.A., F.L.A.

East Malling Research Station, founded in 1913 as the Wye College Fruit Experiment Station, is concerned with the problems arising out of

the culture of fruit plants. It seeks to elucidate the principles underlying cultural operations, including the use of rootstocks for tree fruits, and to relate them to the growth and physiology of the plant and the quality of the fruit. An integral part of the work is the study, directed toward control, of the diseases and pests of fruit and certain diseases of hops; and this includes the improvement and subsequent maintenance of the health status of plant material for propagation, together with the selection and introduction of new varieties.

On 31st March, 1959, the scientific and experimental staff of the station numbered eighty-two.

CURRENT WORK

Pomology. Co-operative field trials of the "new" Mallings-Merton apple rootstocks continued and are expected to provide additional evidence as to their value in widely differing districts. The search for and testing of potential new rootstocks for apple, pear, plum, and cherry continues. A new semi-dwarfing apple rootstock, M.26, has been multiplied for release to the industry.

Studies in the winter storage of cuttings of apple, quince, and plum progressed sufficiently to justify a further programme of experiments to test the possibility of commercial budding of lined-out cuttings within nine months of placing in store. This procedure would provide an attractive and economic alternative to the use of rooted layers from stoolbeds.

Studies have been made of the microscopic characters associated with resistance of apple rootstock and scion varieties to woolly aphid. A new line of investigation of economic interest concerns the anatomical interpretation of "skin quality" in tree fruits and the origin and development of russetting, cracking and other skin blemishes in relation to environmental and cultural factors.

Earlier work on the distribution and extent of the root systems of fruit plants has provided a sound basis for new investigations designed to provide much needed information upon seasonal changes in root-activity, including the potential absorption of water and minerals. A study of the causes of poor setting in Cox's Orange Pippin has also been started, and a survey has been made of irregular cropping of pears in the Eastern Counties.

Progress can be reported in the breeding of soft fruits, particularly directed towards improved fruit size and large strigs in black currants, spinelessness in gooseberries, and increased resistance of raspberries to the virus vector *Amphorophora rubi*. Additional clones of loganberry are under study, and merit comparison with the valuable L.478 reselection of the original East Mallings loganberry selection, recently made available to the industry through Long Ashton Research Station and the Nuclear Stock Association.

Statistics. Access to the electronic computer at Rothamsted has stimulated interest in the fields of component analysis and factor analysis in relation to the study of the growth and cropping of fruit plants and has enabled studies to be undertaken that would otherwise have been impossible. A start has been made on the indexing of the Station's experimental records accumulated over the last forty-five years, to make the data more

easily accessible. Attention has also been given to the urgent task of obtaining information as to the most speedy and appropriate method of restoring land on the experimental farm from which trees have been grubbed to a condition fitting it for further use in research.

Plant Physiology. The scope of research in plant physiology was enlarged by the transfer to the staff of members of the Research Institute of Plant Physiology of the Imperial College of Science and Technology, previously working at East Malling on cognate problems. The research programme was accordingly revised to include studies of leaf area, leaf efficiency, the importance or otherwise of limited spray-damage, and the side effects of spray chemicals upon growth and cropping of fruit trees. In addition, studies of the location and role of growth-substances within the root-system are planned.

The carbohydrate reserves of the fruit plant, and their distribution and utilisation in relation to phases of vegetative and reproductive growth are being investigated in an attempt to define the cycle in terms of the physiology of the *whole* tree in relation to vegetative growth and fruiting. The effect of defoliation, both in relation to carbohydrate reserves and to the degree of spray-damage likely to be sustained by early spur leaves, is also being examined. Studies of growth and form and of the occurrence and influence in stem and leaf of natural growth substances and of their inhibitors have been actively continued.

Biochemistry. Studies of the role of polyphenols in the metabolism of the fruit plant were extended in liaison with the California Institute of Technology, while the investigation of the natural phenolic inhibitors of the apple and pear scab organisms made good progress. The role of phloridzin in tree metabolism also received attention.

Fruit Nutrition and Plant Analysis. The closely related programmes of research under these heads were not enlarged during the year. The approaching termination of certain lines of investigation provided the opportunity, however, for a more active study of the seasonal cycle and the efficiency of uptake of applied nutrients, especially nitrogen, in relation to soil fertility, cultural treatments, and the growth and cropping of the tree. The data from a prolonged "spray culture" experiment on the magnesium and iron nutrition of the plant are being studied, while from field experiments it appears that substantial increases in crop may be obtained from trees suffering from magnesium deficiency by *repeated* foliar applications of magnesium sulphate. This treatment has proved far more effective than soil application.

Extended field experiments are in progress on responses of both tree and small fruits to control of summer soil moisture deficits. Work is also being developed on the inter-relationship of the effects of soil nitrogen and soil moisture on tree growth and fruiting.

Monthly sampling of six year old trees is providing material for determining the changes in mineral composition of whole trees with time, and also for an investigation of the relation of seasonal fluctuations in the organic reserves of the tree to growth and cropping. A survey of cropping in relation to mineral nutrition was made over some 32 commercial orchards

of Cox's Orange Pippin, and a report published. The uptake of aluminium in relation to pH was studied in sand culture.

Plant Pathology. Fire-blight of pears, an important bacterial disease identified in 1958 in our laboratories, was responsible for a serious dieback of the variety Laxton's Superb, and was the subject of intensive collaborative work with the N.A.A.S. Emergency steps were taken to publish and distribute a full account of the disease and its identification to assist in the working of the new Fire-blight Disease Order, 1958. Host range and varietal susceptibility are being determined. The extensive programme of work on the control of bacterial canker of cherries is being extended to include plums.

Continued study of analogues of the naturally occurring inhibitors of fungal growth in Cox's Orange Pippin has yielded promising long-range results in the search for systemic fungicides effective against apple and pear scab. Field trials have indicated that, provided the dosage rate remained constant, lime-sulphur concentrates were effective in the control of scab over a wide range of variation in droplet size, concentration, and rates of application.

Field reports have emphasised the potentially serious nature of *Phytophthora cactorum* as a disease of mature apple trees. A newly devised method of testing the resistance of clonal rootstocks revealed a wide range of resistance offering promise of reducing the damage done by this disease.

Knowledge of the virus pathogens of tree and small fruits and their host ranges has been considerably extended, and field experiments continue to indicate the great advantages to fruit growers of the use of the range of virus-tested propagation material now available to the industry. Virus inactivation by heat has been successfully applied to increase this range, especially in plums. In the soft fruits considerable advances were made in research on the role of leaf-hoppers in the spread of the "aster-yellows" type of virus disease and towards identifying the agents of spread of certain soil-borne virus diseases affecting strawberry.

The intensive investigation of the *Verticillium* wilt disease of hops (together with hop virus diseases) made considerable advances in our knowledge of the working and limitations of the wilt-resistant, or tolerant, hop varieties on the one hand, and of the soil ecology of the fungus pathogen on the other. In the latter studies the fungus has been shown to have very limited powers of survival and transport in soil devoid of alternative weed hosts and infected plant debris.

Entomology. Studies of naturally occurring races of the aphid vector of raspberry virus diseases have assisted the incorporation of resistance to the vector in breeding new varieties.

The long history of the control of Fruit Tree Red Spider Mite entered a fresh chapter when in 1958 direct evidence was obtained of the occurrence of variant races of mites resistant to the hitherto entirely effective acaricide chlorbenside. The nature and development of such resistance is being studied intensively, both in the field and among laboratory-reared populations of mites. Progress was made in the control of both codling moth on apples and the strawberry seed beetle. The role

of migratory nematodes associated with poor growth in re-planted orchards continued to receive attention in an attempt to distinguish effects arising from nematode infestation from those arising from other adverse factors present in the soil.

Plant Protective Chemistry. The relatively cool summer assisted the greenhouse screening tests of chemicals effective in the control of the powdery mildew of apple, attention being concentrated on DNOPC and its analogues. The free phenol was found to be as effective as the crotonate ester. Studies on phytotoxicity embraced a large range of fungicides and insecticides. Earlier work on the intake of copper by foliage enabled a fresh and promising extension of the work to include magnesium and, potentially, other nutrient ions.

Fruit Storage. Collaboration with the Ditton Laboratory in studies of orchard factors influencing the storage life of apples, and of factors affecting the development during storage of fungal infections entered its sixth year. Continuation, for a further two years, of the Station's investigation into the storage capacity of apples from a large number of orchards was unanimously requested by the growers concerned. The work has already enabled the selection of a number of possible Cox-strains for further test and has revealed a possible differential effect of storage conditions on species of *Gloeosporium*.

Studentship. The award of the first of the studentships provided by private subscriptions and named the V. H. Blackman Postgraduate Studentship, was made in 1958 for research into the natural control of Fruit Tree Red Spider Mite.

A more detailed account of the work of the Station is given in its Annual Report.

AGRICULTURAL AND HORTICULTURAL RESEARCH STATION

Long Ashton, Bristol

Director: Professor H. G. H. Kearns, O.B.E., B.Sc., Ph.D., Dip.Agric.

POMOLOGY

Head of Department: L. C. Luckwill,
B.Sc., Ph.D.

D. L. Abbott, B.Sc.

E. W. Hobbs, B.Sc., N.D.H.

R. R. Williams, B.Sc., Dip.Hort.sci.

NUTRITION OF FRUIT CROPS

Head of Department: C. Bould, M.Sc., Ph.D.
D. G. Hill-Cottingham, M.Sc., Ph.D., A.R.I.C.

CHEMISTRY

Head of Department: J. T. Martin,
D.Sc., Ph.D., F.R.I.C.

D. Woodcock, D.Sc., Ph.D., F.R.I.C.
(Organic Chemistry)

W. D. E. Thomas, B.Sc., Ph.D., F.R.I.C.
(Physical Chemistry)

E. Somers, M.Sc., Ph.D.

E. J. Skerrett, Ph.D., A.R.I.C.

C. P. Lloyd-Jones, B.Sc., A.R.I.C.

ENTOMOLOGY

Head of Department: H. G. H. Kearns,
O.B.E., B.Sc., Ph.D., Dip.Agric.

S. H. Bennett, B.Sc., Ph.D.

N. G. Morgan, B.Sc., Ph.D.

A. Stringer, B.Sc., A.R.C.S.

C. G. L. Furmidge, B.Sc., Ph.D., A.R.I.C.

Secretary: A. L. Leggett, A.C.A.

PLANT PATHOLOGY

Head of Department: R. W. Marsh, M.A.

R. J. W. Byrde, B.Sc.(Hort.), Ph.D.

A. T. K. Corke, B.Sc., Ph.D.

PLANT PHYSIOLOGY

Head of Department: E. J. Hewitt,
B.Sc., Ph.D., A.K.C.

CIDER AND FRUIT JUICES

Head of Department: A. Pollard, M.Sc., Ph.D.

G. C. Whiting, B.Sc., Ph.D.

L. F. Burroughs, B.Sc., Ph.D., A.R.I.C.

F. W. Beech, B.Sc., Ph.D., A.R.I.C.

Miss M. E. Kieser, B.Sc., A.R.I.C.

C. F. Timberlake, M.Sc., Ph.D., A.R.I.C.

J. G. Carr, B.Sc., Ph.D.

DOMESTIC FOOD PRESERVATION

Head of Department: Miss B. A. Crang, B.Sc.

WILLOWS

Head of Department: K. G. Stott, B.Sc.

STATISTICS

Head of Department: G. M. Clarke,
M.A., F.R.S.S., Dip.Stat.

SCIENTIFIC LIAISON

Head of Department: M. Greenwood,
O.B.E., M.Sc.

Librarian: P. R. Colegate

The Station, which is administered by the University of Bristol, studies all aspects of fruit growing, with special reference to the problems of growers in the West Midlands and the South-west. In addition it undertakes research into the manufacture of cider, perry, and fruit juices, the domestic preservation of fruit, vegetables, meat and poultry, and the cultivation and utilisation of willows, and serves as the national centre for advice on these subjects. It also advises the Colonial Office on spray techniques for the control of pests and diseases in tropical crops.

On 31st March, 1959, the scientific and experimental staff numbered seventy-three.

CURRENT WORK

The increase in apple production resulting from post-war plantings has given urgency to the adequate utilisation of cull fruit. As uptake by the cider industry cannot be expected to increase significantly, a major outlet for fruit is being sought in the development of naturally cloudy apple juice. Experimental trials and demonstrations of opalescent juices and of blends with citrus and other fruit juices have been followed by trials on a larger scale and by consumer acceptance tests; these have attracted the attention of growers and manufacturers and are being extended.

Further studies have been made of the chemical and microbiological changes that occur during the fermentation of cider and perry. One surprising result has been the discovery that the acetic acid bacteria, which contaminate fruit collected from the ground, not only survive but multiply during anaerobic fermentation.

In the search for an agent that will induce parthenocarp in apples and pears, thus making them less dependent on insect pollination and able to set a crop despite frost damage, tests of auxins and other types of plant hormone have been regularly made during the past fourteen years. Some success has recently been achieved with gibberellic acid, which has stimulated parthenocarp in one variety of apple and two varieties of pear. Other work with growth substances has included a study of the resistance that some varieties of fruit plant show to 2:4-dichlorophenoxyacetic acid, employed for weed control in fruit plantations. Using materials labelled with radioactive carbon it has been found that resistant types of apple and currant have the ability to break down the growth substance rapidly to carbon dioxide.

Micro methods of analysis that will determine the amount of spray material present on small areas of plant surface are essential to the study of the efficiency of spraying techniques, of the mechanisms of toxic action and of the likelihood of consumer hazards. A method for the determination of small quantities of dieldrin, applicable with lower sensitivity to endrin, has now been evolved; methods previously devised for mercury and copper have been used in studying deposits on coffee in Kenya and on tobacco in N. Borneo. Fluorescent tracers have proved useful for delineating spray patterns and have been successfully used with Abaca hemp in North Borneo.

Work has continued on the relationship between the molecular structure and the biological activity of growth substances and fungicides, and on the metabolism of organic compounds by micro-organisms. The resistance of some varieties of apple to the brown rot fungus (*Sclerotinia fructigena*) has been shown to depend on the presence in the fruit of oxidised polyphenols that reduce the pectolytic activity of the fungal enzymes. In tests of various polyphenols isolated from apples, oxidised catechins and leucoanthocyanins have been found to have a greater inhibitory effect than oxidised chlorogenic acid.

Insect pests studied include the leaf hoppers infesting apples and the Willow weevil, which causes deformation in willow rods and severe damage to the stools. The biology of the Big Bud mite of black currants is under reinvestigation as a basis for further work on control measures and on the transmission of the virus causing reversion. Mechanical methods evolved for the determination of mite and egg populations have proved much more rapid and reliable than conventional visual estimates based on bud size. The behaviour of the mite is influenced more closely by the physiological development of the plant than had been supposed; its dissemination appears more dependent on transmission by insect vectors and less dependent on wind transport than was suggested by previous workers. Experiments that will, it is hoped, lead to a method of control better than the present single or double grape-stage application of contact acaricides are in progress.

Two new spray nozzles designed at Long Ashton are now under test: one uses air at pressures up to 100 lb./sq. in.; the other is a multivane atomiser that uses a larger volume of air at a pressure of 2 lb./sq. in. and is capable of delivering up to 23 gallons of spray fluid per minute. In both nozzles the range of droplet sizes is adjustable and the risk of choking is eliminated by the use of wide apertures.

Further information about the Station's work will be found in its published Annual Report.

A.R.C. UNIT OF PLANT NUTRITION (MICRO-NUTRIENTS)

Long Ashton, Bristol

Honorary Director: Professor T. Wallace, C.B.E., M.C., D.Sc., F.R.I.C., V.M.H., F.R.S. (Emeritus Professor of Horticultural Chemistry, Bristol University)

PLANT PHYSIOLOGY

E. J. Hewitt, B.Sc., Ph.D., A.K.C.

ORGANIC CHEMISTRY

A. H. Williams, M.A., B.Sc.

NUTRITION OF MICRO-ORGANISMS

D. J. D. Nicholas,
D.Sc., Ph.D., A.K.C., F.R.I.C.

INORGANIC CHEMISTRY

H. M. Stevens, B.Sc., Ph.D.

PLANT BIOCHEMISTRY

H. E. Davenport, B.Sc., Ph.D.

SOIL BIOLOGY

R. A. Webb, B.A., D.Phil.

The main object of the Unit is to determine the role of micronutrients in the metabolism of higher plants and micro-organisms. The Unit was established in 1952; it was disbanded at the end of September, 1959, when the Director retired, but arrangements have been made for the work to continue at Long Ashton Research Station.

On 31st March, 1959, the scientific and experimental staff of the Unit numbered twenty.

CURRENT WORK

Plant Physiology. Further studies of the synthesis *in vivo* of nitrate reductase, using detached leaf tissues of cauliflower, have shown that two compounds related to tryptophane and one analogue of arginine can inhibit synthesis; on the other hand, serine markedly stimulates production of the enzyme. The inhibition already observed when actidione is infiltrated into leaves has now been found to occur when this compound is taken up by the plant roots. Hydroxylamine reductase, prepared from extracts of vegetable marrow, appears to require manganese for activity: preparations from manganese-deficient plants are inactive until manganese is added to the extract. Studies of aldehyde oxidase in potato have been continued, and a preliminary investigation has been made, in collaboration with the National Institute for Research in Dairying, of the uptake of oestrogens by plants.

Nutrition of micro-organisms. Further work on the enzymes involved in the assimilation of nitrate by the fungus *Neurospora crassa* has shown that nitrate reductase formation is strongly inhibited by ammonia and by several amino acids; that nitrite reductase, previously shown to be activated by iron and manganese, is a flavoprotein containing these two metals; that,

contrary to published reports, hydroxylamine reductase is unable to oxidise ammonia to hydroxylamine, and that glutamic hydrogenase, which can utilize either DPNH or TPNH, requires zinc for its activity. Work with hydrogenase and with nitrogen-fixing enzymes in *Azotobacter vinelandii* and *Clostridium pasteurianum* has continued and preliminary nutritional and enzymic studies have been made with nitrifying and denitrifying bacteria.

Biochemistry. Observations on the effect of nutritional conditions on the tetrapyrrolic pigments of higher plants have been continued and a method has been devised for the estimation of the individual cytochrome components of chloroplasts. In studies of the photochemical activities of isolated chloroplasts it has been found that a purified leaf protein fraction, previously shown to catalyse the photochemical reduction of haem-protein compounds, is also very active in catalysing the reduction of triphosphopyridine nucleotide. This latter activity is stimulated when it is coupled to photophosphorylation.

Organic Chemistry. The investigation of the phenolics of apple species has considerably expanded our knowledge of the dihydrochalcone group of compounds. The results are of taxonomic interest, as some of the compounds seem to be associated with certain groups of species. The flavonol glycosides show no such clear-cut distinctions, though there are differences in the relative importance of the individual compounds in the various parts of apple and pear trees.

Inorganic Chemistry. Work has begun on the chromatographic separation and determination of the trace metals normally occurring in soils. A *n*-butanol-HCl-H₂O eluant gave good individual separations of zinc and molybdenum from a mixture containing also iron, cobalt, nickel, copper, manganese and magnesium; the last group was resolved in an acetone-HCl-H₂O eluant. It is hoped to adapt these methods to the examination of soils and plant materials.

Soil Biology. In further work on the interrelationship of microbiological activity, carbohydrate supply, crumb structure and mineral deficiency, the effects of sulphur, copper, molybdenum and calcium deficiencies have been studied in a sandy tropical soil. With cellulose as the carbohydrate source these deficiencies impaired, to various degrees, the aggregation of soil particles. Changes in the water-solubility of some of the nutrients appeared to occur during the formation of crumbs and during their subsequent disintegration. To determine whether these changes affect the availability of the nutrients it is proposed to assay test plants grown in the treated soils. Preliminary trials of a chromatographic method of assay are being made with tomatoes grown in sand cultures containing graded amounts of copper, zinc and manganese.

SCOTTISH HORTICULTURAL RESEARCH INSTITUTE

Mylnefield, Invergowrie, by Dundee

Director: T. Swarbrick, M.Sc., Ph.D.

PLANT PATHOLOGY

Head of Department: C. H. Cadman,
B.Sc., Ph.D., F.R.S.E.

VEGETABLE CULTURE

Head of Department: C. North, M.Sc., Ph.D.

POMOLOGY

Head of Department: C. A. Wood,
B.Sc., Ph.D.

GENETICS

Head of Department: G. M. L. Haskell,
B.Sc., Ph.D.

CROP PHYSIOLOGY

Head of Department: G. L. Hodgson,
M.A., D.Phil.
C. G. Guttridge, B.Sc., Ph.D.

MYCOLOGY

Head of Department: A. R. Wilson,
B.Sc., M.S., Ph.D.

WEST OF SCOTLAND UNIT

Auchincruive, Ayr

Officer-in-charge: R. D. Reid
Miss I. G. Montgomerie, B.Sc., Ph.D.

Secretary: A. B. Ross, A.I.A.C.

The Institute, set up in 1954, has established main lines of research bearing directly on problems of the horticultural industry in Scotland. These are concerned very largely with the growing of soft fruit and vegetables under climatic conditions rather different from those of the South. They include breeding and varietal studies, crop physiology and the control of pests and diseases important in Scotland.

On 31st March, 1959, the scientific and experimental staff of the Institute numbered twenty-six.

CURRENT WORK

Pomology. (Fruit Culture.) Variety trials and investigations into the effect of cultural practices on yield and quality are continuing with raspberries, strawberries and black currants. The raspberry growing industry is changing its emphasis from bulk production for the jam trade to more specialised production for canning and freezing and the work of the Department over the last five years has helped to provide growers with the information they need in the new circumstances.

A substantial raspberry breeding programme aimed at producing varieties with more acceptable qualities for the canning and freezing industries is under way. Upwards of 2,000 seedlings will be fruiting for the first time in 1960. A substantial black currant breeding programme is also under way and the first major batch of seedlings will be fruiting in 1960.

Investigations into the use of chemical herbicides for weed control in soft fruit plantations have been intensified and are now one of the main lines of work. They are being carried out in close liaison with the Unit of Experimental Agronomy at Oxford. One of the major problems appears to be the possible residual effect of the more effective materials, since these fruit crops are grown in rows and applications of herbicides are therefore made to the same place for several years running. The Department is also co-operating with the West of Scotland Agricultural College and the National Institute of Agricultural Engineering, Howden, in work on the use of herbicides in potatoes.

Vegetable Culture. The main objective is to increase the range of vegetables that can be grown commercially in Scotland. The canning and freezing industry is still expanding its processing facilities in Scotland and the demand for suitable vegetables at suitable times is considerable. Variety trials using varieties from all over the world are used to give an initial assessment of possible usefulness and a breeding programme is initiated whenever there is a reasonable prospect of success. French beans in particular are being worked on. Breeding work in winter heading cabbage and brussel sprouts is being continued and a number of useful lines are now being fixed.

Crop Physiology. Studies have continued on the effect of environment upon growth and development in the strawberry plant using small specialised controlled environment cabinets. The results obtained suggest that the photoperiodic regulation of growth and flowering in the strawberry acts through a hormone which promotes vegetative growth and inhibits flowering. This finding is contrary to the widely accepted view that flowering is promoted by the positive action of a substance which has been called a florigen, and may explain why despite much effort no such substance has been isolated.

Radio-active isotopes are being used to study translocation and accumulation in the plant.

Field experiments on the use of maleic hydrazide to inhibit runner formation, and defoliation to encourage flower formation, are in progress; and work on cold storing of runners is continuing.

Genetics. The general theme is the study of genetical aspects of adaptation in horticultural crop plants. Work is continuing on the "yellows" complex in strawberries, and the department is co-operating with Pomology and Vegetable Culture and the West of Scotland Unit in their breeding programmes.

Virology. The work of this department is concentrated mainly on the soil-borne viruses. Close liaison is maintained with Rothamsted.

One of the soil-borne viruses isolated at Mylnfield from raspberry and called Raspberry Ringspot Virus has now been isolated from each of three samples of sweet cherry sent from Switzerland and known to be suffering from Pfeffinger disease. Viruses isolated from cherry in Germany and from cherry in England by Posnette have also been found to be strains of raspberry ringspot.

The virus earlier named raspberry yellow dwarf has been found by serology to be related to Arabis Mosaic, a virus described some years ago by Cambridge workers. The virus has now been isolated at Mylnfield from horseradish from Denmark and elderberry from Perthshire.

It is too early to evaluate the implications of these findings, but it may be concluded that the soil-borne viruses have a wide distribution and that the same virus may cause quite different symptoms in different plants.

The mechanism of transmission of the soil-borne viruses isolated at Mylnfield is being studied and transmission of one of these viruses has now been obtained in a sterile medium by the nematode species *Xiphinema*.

Mycology. The investigations into the field behaviour of *Botrytis* have confirmed previous findings that the main concentration of air borne spores in raspberry plantations occurs about mid-day with a secondary peak just before dusk. The mechanism of spore release is being studied.

Differences in varietal susceptibility to infection are considerable. In 1958 (a year of heavy infection) only about 7 per cent of the fruit of Malling Jewel raspberry was infected compared with 51 per cent of Malling Promise.

Field control methods using all the known fungicides are being studied in detail. Captan is the most promising material of those commercially available.

The study of Grey mould (*Botrytis*) in glasshouse crops, tomatoes and lettuce is continuing. The acquisition of some additional glasshouses will enable this work to be put on a firm basis and more precise results are to be expected next year.

West of Scotland Unit. The wet summer of 1958 followed by the very dry summer of 1959 provided ideal conditions for the field testing of strawberries for resistance to *Phytophthora fragariae*.

Of the seedlings raised between 1947 and 1951 inclusive none have been found to combine the necessary characters of yield, quality and disease resistance in sufficient measure to be worth considering as new commercial varieties. A few have shown outstanding individual characters, e.g. high yield, good quality or high disease resistance, and these have been retained for future breeding.

A change in breeding programme in 1952-53 has produced a number of seedlings which show distinct promise and these are now going into the field trials at Auchincruive and Mylnfield.

New sources of resistance to *P. fragariae* are being sought mainly in seedlings of *F. virginiana*, using seed collected in the wild.

Studies in the inheritance of resistance and the isolation of physiologic races of the fungus have been continued.

The two varieties Talisman and Redgauntlet have proved commercially acceptable and now account for upwards of 60-70 per cent of the strawberry acreage in the U.K. At least two authentic cases of 8½ tons per acre for Talisman and 7 tons of Redgauntlet have been reported for the 1959 crop with 5 and 6 ton crops quite general.

A more detailed account of the work of the Institute is to be found in its Annual Report.

WYE COLLEGE

Department of Hop Research

Wye College (University of London), Ashford, Kent

Head of Department: H. S. Darling, B.Sc., M.Agr., A.I.C.T.A.

Senior Scientific Staff:

F. C. Thompson, B.Sc., M.Sc.(Agric.), A.R.I.C.

R. A. Neve, B.Sc.(Agric.), Dip.Agric.sci.

Hop research at Wye College covers the majority of the problems which arise in the growing, picking and drying of the hop crop. Work on virus

diseases and *Verticillium* Wilt is the responsibility of East Malling Research Station. The main lines of research at Wye comprise plant breeding, chemistry (including plant nutrition and hop resins), pests and insecticides, Downy Mildew Disease (*Pseudoperonospora humuli*) and crop growth. Work on hop picking and drying has become increasingly associated with engineering techniques and the College shares the responsibility for such research with the National Institute of Agricultural Engineering.

On 31st March, 1959, the scientific and experimental staff of the Department numbered nine.

CURRENT WORK

Hop breeding is concerned mainly with the production of wilt-tolerant varieties that are commercially acceptable. Three English-type diploid seedlings produced in collaboration with East Malling Research Station have been propagated on a large scale and are to be planted out in farm trials on three wilt-infected sites in the winter of 1959-60. Polyploid breeding methods are being used extensively. A bulk of triploid seedlings derived from a standard commercial variety were picked mechanically for the first time. The results were promising in that the cones, which were largely seedless, appeared to show resistance to the shattering action of the picking machine. Selection work is in progress with the wilt-sensitive varieties Goldings and Fuggles to provide improved clonal strains for use in wilt-free areas.

Long-term manurial experiments continue to provide basic data on the major element requirements of the hop plant under commercial conditions. There is increasing evidence that the phosphate status of the average established hop garden is high enough to allow good crops to be grown with much smaller annual applications of phosphate than are usually given. Evidence is also accumulating to show that excess of nitrogen reduces yields.

Results of current research on the control of the hop aphid by systemic insecticides suggests that dimefox (bis dimethylamino-fluorophosphine oxide) may increase yields to a greater extent than can be attributed to its insecticidal ability.

Investigations on basal spike formation in Downy Mildew Disease have made satisfactory progress. They include research both on the biological aspects of the problem and on control under field conditions. Hill dusting with copper fungicides during the growing season shows promise of at least partial control. Trials with streptomycin have given disappointing results. Research on the assessment of varietal resistance to Downy Mildew continues.

Studies on hop growth include investigations into the seasonal accumulation and utilisation of carbohydrate reserves in the rootstock. Preliminary work has shown that the onset of dormancy in late summer and early autumn is accompanied by the development of a relatively large food storage organ by a small leaf area. Where dormancy is prevented by supplementary light and heat, leaf and shoot growth continue but little food accumulation occurs.

The successful application of mist propagation techniques to hops has made possible the production of large batches of uniform clonal plant

material for experimental use. This advance, together with increased knowledge on the growth of hops under glass in winter months, has greatly assisted many aspects of hop research.

Wirework has been erected over a new height and spacing trial. A new hop picking machine has been installed at the College. These two developments jointly make possible a number of investigations on mechanical hop picking in collaboration with the N.I.A.E.

VEGETABLES

NATIONAL VEGETABLE RESEARCH STATION

Wellesbourne, Warwick

Director: James Philp, B.Sc., Ph.D.

Deputy Director: D. W. Wright, M.A.

PLANT BREEDING

Head of Department: J. C. Haigh,
B.Sc., Ph.D., A.R.C.S., A.I.C.T.A.

H. Holland, B.Sc.

A. G. Johnson, B.Sc., Ph.D.

L. E. Watts, B.Sc.

CHEMISTRY

Head of Department: F. Haworth,
B.Sc., Ph.D., Dip.Ag.sci., A.R.I.C.

S. P. Spragg, B.Sc., Ph.D.

PHYSIOLOGY

Head of Department: E. J. Winter,

M.C., M.Sc.

J. K. A. Bleasdale, B.Sc., Ph.D.

IRRIGATION

Head of Department: E. J. Winter,
M.C., M.Sc.

Secretary: G. Lesson, B.Sc.(Econ.), A.C.I.S.

ENTOMOLOGY

Head of Department: D. W. Wright, M.A.

J. A. Dunn, M.Sc., Ph.D.

G. A. Wheatley, B.Sc.

PATHOLOGY

Head of Department: W. G. Keyworth,
B.Sc., Ph.D., A.R.C.S., D.I.C.

A. G. Channon, B.Sc.

J. A. Tomlinson, B.Sc., Ph.D.

WEEDS

Head of Department: H. A. Roberts, B.Sc.

STATISTICS

Head of Department: J. A. Nelder, M.A.

Librarian: Miss B. M. Moore, N.D.D.H.

The Station with its Sub-Station at Paglesham, Essex, was established in 1949, and its work is directed towards the solution of a wide range of important practical problems in many vegetable crops, and towards the acquisition of scientific knowledge which will lead to advances in the practice of vegetable production. The subjects of research fall into eight sections: the breeding of improved varieties, the improvement and maintenance of soil fertility, the investigation of factors affecting crop growth, the study of irrigation, the control of pests, diseases, and weeds, and the improvement of field experimentation.

On 31st March, 1959, the scientific and experimental staff of the Station numbered forty.

CURRENT WORK

The technique of inbreeding, followed by crossing of inbred lines, gives promise of producing hybrid varieties of Brussels sprouts and onions showing distinct improvements in crop uniformity and yield. Prospects are good of producing a Detroit type of red beet which will not bolt when sown early.

In long-term field experiments, deep cultivation continued to benefit Brussels sprouts and leeks, but peas responded better to the shallow cultivations. Of the manurial treatments, farmyard manure each year has produced the largest increase in yield but apparently its continued application during the past five years has not produced cumulative effects on yield. Further experiments have confirmed that one top dressing of inorganic nitrogenous fertiliser produced at least as high a yield of spring cabbage as did the same total amount of fertiliser applied in three small doses. Changes in the amounts of sugars and organic phosphates in red beet plants, resulting from periods of cold treatment, were similar to those taking place in plants which were about to flower. Using germinating peas it has been shown that the reduction of protein disulphide groups by oxidised glutathione is an essential reaction in mitosis and that maleic hydrazide stops mitosis by interfering with this reaction.

The work on competition between vegetable crops and annual weeds is being continued. The effect of different factors on the growth rate of certain crops in the Chemistry Section's manurial experiments is being determined by the Physiology Section in an attempt to explain the crop results obtained.

The Statistics, Physiology and Irrigation Sections are collaborating in a study of plant growth rates and the relative sizes of different parts of the plant as affected by external factors.

The Irrigation Section is investigating the effects of different watering treatments on the growth of vegetable crops, with a view to establishing irrigation methods which will combine the most efficient use of water and equipment with the maximum benefit to the crop.

The detailed study of the natural regulation of cabbage root fly numbers over the past three years has demonstrated the major part played by egg-eating predatory insects in the soil. The reduction of the pest population, however, is insufficient to prevent considerable crop loss so that chemical control of the remaining population is necessary with the more valuable brassica crops. Several methods of control have been developed which use local high concentrations of insecticide and do not seriously affect the predator population. Insecticides occurring at low concentrations throughout the soil may lead to an increase in pest damage through an adverse effect on predators.

Research on silvering disease of red beet, which has severely affected seed crops of the variety Cheltenham Green Top, has shown that the best method of control is to treat the seed with streptomycin which is now available for this purpose. Some preliminary work using aldrin for the control of clubroot in summer cabbage has given interesting results.

Further work with the herbicide dinoseb (amine) has confirmed its value as a residual pre-emergence spray for use in crops of runner beans and dwarf French beans. Applications at a rate twice that normally used in the post-emergence treatment of pea crops have given excellent control of annual weeds without damage to the beans. Experiments are in progress to determine the potential uses in vegetable crops of a number of other residual herbicides and a bioassay technique is being used to follow the course of their breakdown in the soil. Work on the effects of sub-lethal

doses of growth-regulator herbicides on vegetable crops is being continued and is yielding information which will be useful in the diagnosis of crop injury resulting from spray drift.

The Statistics Section is called upon by the National Agricultural Advisory Service for assistance in the design and analysis of experiments on vegetable crops. Investigations are being continued on the nature and extent of the many extraneous factors which reduce the accuracy of field experiments.

Further information on the work of the Station can be obtained in the Station's Annual Reports.

WEEDS

A.R.C. UNIT OF EXPERIMENTAL AGRONOMY

Department of Agriculture, University of Oxford

Honorary Director: G. E. Blackman, M.A., F.R.S.

(Sibthorpe Professor of Rural Economy, University of Oxford)

Assistant Director: E. K. Woodford, O.B.E., M.Sc., Ph.D., D.I.C.

SELECTIVE TOXICITY AND HERBICIDAL ACTION

R. J. Chancellor, B.A.

J. G. Elliott, M.A.

J. D. Fryer, M.A.

K. Holly, B.Sc.(Agr.), Ph.D.

L. Kasasian, B.Sc.

C. C. McCready, M.A., D.Phil.

Miss D. J. Osborne, M.Sc., Ph.D.

R. G. Powell, B.A.

NEW CROPS—PARTICULARLY OIL SEED CROPS AND HYBRID MAIZE

E. S. Bunting, B.Sc., Ph.D.

The long term programme of research undertaken by the Unit of Experimental Agronomy is divided into two parts. One series of investigations relates to a broad based study of chemical methods of weed control, ranging from fundamental work on the factors determining selective action to extensive field trials concerned with the development of practical methods of weed eradication. The other part has as its aim the assessment of the environmental and agronomic conditions which will permit the cultivation of new or unusual crops in Great Britain.

On 31st March, 1959 the scientific and experimental staff of the Unit numbered twelve.

CURRENT WORK

The present programme of fundamental research is in the main a continuation of investigations already started. Most emphasis is at present being given to studies of the entry and movement of phytotoxic compounds, which are engaging the attention of both members of the Unit and research workers in the Department of Agriculture. It has been demonstrated that the course of uptake of some growth regulators is anomalous and that the pattern is dependent on the species and the chemical structure of the auxin.

Once a compound has penetrated the leaf surface its subsequent distribution is dependent upon cell to cell movement, translocation in the phloem

and transport in the xylem. Movement of growth regulators in undifferentiated tissue has been investigated in some detail and it is evident that the extent of movement and the amounts moved are linked with the chemical structure. Other experiments have shown that the ability of different types of herbicides to move out of the treated leaf are widely divergent. Some compounds within a short time are present throughout the rest of the plant while others remain within the leaf.

These basic studies are now being followed up by field investigations to ascertain to what extent and under which conditions herbicides applied to the leaves are transported to the underground systems of perennial weeds. Two species have been selected for the initial programme, *Agropyron repens* (couch grass) and *Pteridium aquilinum* (bracken), while the principal compounds being employed are 2,2-dichloropropionic acid (Dalapon) and 2,4-dichlorophenoxyacetic acid (2,4-D). In addition other experiments, more particularly with bracken, have been laid down to test the influence of time of application, compound, dose and formulation on the degree of control.

Further research to improve the efficiency of pre-emergence spraying has been undertaken and an experimental machine has been devised whereby the herbicide can be incorporated in the soil at the time of drilling the seed. It is thought that this technique will be of considerable value in some row crops.

The role of herbicides in the renovation of low-grade grassland is being further explored, together with other developmental work at the University Field Station and elsewhere.

At present research on new crops centres round the further appraisal of hybrid maize for grain and silage production and opium poppy for its seed and alkaloids. It is clear that a number of European hybrids of maize are capable of giving high yields of silage. In the poppy the aim of the breeding programme is to combine earliness and a short stem with a high yield of seed and alkaloids in the capsule.

A.R.C. UNIT OF PLANT GROWTH SUBSTANCES AND SYSTEMIC FUNGICIDES

Wye College (University of London), Ashford, Kent

Honorary Director: Professor R. L. Wain, D.Sc., Ph.D., F.R.I.C.
(Professor of Agricultural Chemistry and
Head of Department of Physical Sciences)

Senior Scientific Staff:

C. H. Fawcett, M.Sc., Ph.D., A.R.I.C.

D. M. Spencer, B.Sc., Ph.D.

The Unit is concerned with research in two quite different fields of work. On the one hand attention is given to those chemicals, often referred to as growth hormones, which control the growth and development of plants. The other line of work is concerned with chemicals which might prove useful in controlling plant diseases caused by fungi. Fundamental aspects are stressed in both lines of investigation and, whilst the main approach is biochemical, plant physiological and pathological studies are also carried out.

On 31st March, 1959, the scientific and experimental staff of the Unit numbered seven.

CURRENT WORK

Further information is being obtained on the various structural features which must be present in the molecule of an organic compound in order that it may show activity as a growth substance. Such investigations are of value in the search for new active compounds, a number of which have been discovered by the Unit, but this research is also useful in helping to elucidate the important problem of how growth substances exert their biological effect. Continued progress has been made in these studies on mode of action and other properties of the molecule which may be of importance in relation to its biological activity are receiving attention.

Investigations have continued on the identification of growth hormones which occur naturally in plants and during the past year the hormone which is present in certain plant tumour growths has been studied. For this work large quantities of crown gall tissue were grown on the stems of tomato plants; the hormone present was identified and shown to occur in greater quantity than in healthy stem tissue.

Studies on breakdown within the plant of acids related to plant growth substances have continued and the investigations have now been extended to include bacteria. A bacterium isolated from soil has been shown to be capable of degrading substances of this type in the same way as they are broken down in the plant. These findings have led to studies on selective bactericidal action. In other work, naturally occurring gibberellin-like substances have been extracted from plant tissues and the role played by this group of substances in cell physiology is being investigated.

In the research on fungicides, two groups of promising chemicals are being investigated; many new compounds are being synthesised for this work which is yielding useful information on structure/activity relationships. A study is also being made of the production of fungitoxic materials by healthy plant roots. Much attention, however, is still being given to the antifungal compound which is present in the stem and root tissues of the seedlings of broad bean (*Vicia faba*). Some progress has been made in the isolation of this compound but only little is yet known of its chemical nature.

PESTS AND DISEASES

A.R.C. UNIT OF INSECT PHYSIOLOGY

Department of Zoology, Downing Street, Cambridge

Director: Professor V. B. Wigglesworth, C.B.E., M.A., M.D., B.Chir., F.R.S.

Senior Scientific Staff:

J. W. L. Beament, M.A., Ph.D.
W. A. L. David, M.A., Ph.D.
J. S. Kennedy, M.Sc., Ph.D.
A. D. Lees, M.A., Ph.D.

A. Milne, M.A., D.Sc., Ph.D., F.R.S.E.
J. E. Treherne, B.A., Ph.D.
R. Laughlin, B.A.

The Unit was established in 1943 to carry out fundamental research on the physiology of insects, particularly in fields which were likely to prove of direct or indirect value in the control of insect pests.

On 31st March, 1959, the scientific and experimental staff of the Unit numbered ten.

CURRENT WORK

The properties of the insect cuticle and egg shell. This subject was early selected for detailed study, because these properties determine both the survival of the insect in the dry terrestrial environment in which it lives, and the penetration of insecticides. It was found that the waterproofing of the cuticle is dependent upon a thin layer of wax deposited on the surface. The wax is much harder and has a higher melting point in those insects which are most resistant to desiccation. If the temperature is raised a point is reached (somewhat below the melting point of the wax) at which there is a more or less abrupt increase in transpiration. It was also shown that the wax is protected by another layer, termed the "cement layer", poured out over its surface from the dermal glands. But in spite of this, the impermeable layer is readily injured if the insect moves in contact with fine dusts or if it burrows in the soil. Insects abraded in this way lose water very rapidly when they are exposed to dry conditions, and they show an increased sensitivity to insecticides applied to the surface of the body.

The extension of this work to the insect egg shell showed that the same general factors are concerned in waterproofing. The impermeable waxes, however, are commonly laid down, not by the mother over the surface of the egg, but by the oocyte itself as a very thin layer on the inside of the shell. In the Fruit Tree Red Spider mite, on the other hand, the main factor in the highly efficient waterproofing of the egg is a layer of a peculiar waxy substance discharged over the egg by the female during oviposition. A rather different type of waterproofing grease is similarly added to the eggs by the female of the Sheep Tick *Ixodes*. The respiration of these exceedingly waterproof eggs is often provided for by a limited number of perforations which lead into an air-filled sponge with submicroscopic cavities that lines the inside of the shell.

The cockroach differs from most other terrestrial insects in having a mobile soft grease which forms the waterproofing layer. This grease consists, in fact, of quite hard waxes in a volatile solvent. On exposure to the air the solvent slowly evaporates leaving a hard wax.

Doubt has been cast by some authors on the reality of the abrupt change in permeability of the wax layer when the temperature is raised. But during the past year an improved apparatus has been devised for the accurate control of temperature and for the measurement of temperature at the actual surface of the cuticle. By this means it has been proved that the increase in permeability at the critical temperature is in fact much more abrupt than had previously been supposed. Furthermore, there is a secondary thin layer of wax which lies on the outer surface of the cement layer. This covering has a higher critical temperature than the primary wax layer and it adds greatly to the efficiency of the waterproofing system.

A.R.C. VIRUS RESEARCH UNIT

Huntingdon Road, Cambridge

Director: K. M. Smith, C.B.E., D.Sc., Ph.D., F.R.S.

Senior Scientific Staff:

R. Markham, M.A., Ph.D., F.R.S.

J. D. Smith, M.A., Ph.D.

J. H. Hitchborn, B.Sc., Ph.D.

M. W. Rees

D. B. Dunn, M.A., Ph.D.

The work of the Unit is concerned mainly with the investigation of viruses of plants, insects and bacteria, and the diseases which they cause. In addition, because of their importance to viruses, the general properties of the nucleic acids from a number of sources are also being studied.

On 31st March, 1959, the scientific and experimental staff of the Unit numbered ten.

CURRENT WORK

Fundamental work on the insect viruses is being continued; the method of multiplication of these viruses and their shape and general anatomy are being studied by means of new staining methods for electron microscopy. Cross-transmission of an insect virus between different orders of insects has been achieved for the first time, and this, combined with experiments to stimulate viruses latent in insects, has led to the discovery of new viruses in hitherto unrecorded hosts.

In collaboration with entomologists in California a virus affecting the citrus red spider has been isolated. This is the first record of a virus disease in the Arachnida.

The use of viruses in the biological control of insect pests has been continued and considerable success has been achieved against the pine sawfly in various places.

The plant viruses are being studied from the chemical and biological points of view. A new tomato virus has been discovered in Guernsey and is under investigation.

Studies on the change in susceptibility of virus to inactivation by ultra-violet light irradiation are being continued. Photo-reactivation of a strain of potato virus Y inactivated *in vitro* has been demonstrated.

Work is also being carried out on the soil-transmission of plant viruses and the interactions between two viruses in the same host.

In the biochemical work, the distribution of the minor constituents of a number of ribonucleic acids has been investigated, and it has been found that these substances, which include "pseudouridine" and several methylated purines and pyrimidines, are largely associated with the "soluble" ribonucleic acid fraction, suggesting that they may be concerned with amino acid activation.

A new sugar has been recognised in "ribonucleic" acids and has been identified tentatively as 2-O-methyl ribose. The quantity found is fairly small and none has been detected in plant virus ribonucleic acids.

In collaboration with Drs. Lipkin and Cook of St. Louis, Mo., U.S.A., the substance causing the activation of liver phosphorylase has been found

to be adenosine 3':5'-phosphate. This compound is of some chemical interest because of its unexpected structure, and it has been synthesised from adenosine triphosphate and adenosine 5'-phosphate.

The amino acid (ϵ -N-methyl lysine) has been isolated from bacterial flagellar protein in collaboration with Mr. Ambler of the Biochemical Laboratory, Cambridge. This amino acid is the only new one to have been identified as a constituent of proteins for a number of years, and it is quite possible that it may have been overlooked in many other proteins because of its similarity to lysine.

The polyamine present in several plant viruses is being examined with a view to establishing its constitution and function. Model experiments using spermidine, which is closely related to the unknown amine, have shown that these substances have a profound effect on the physical properties of some viruses.

One problem of considerable interest which is being investigated is the nature of the changes which occur when the "cowpea" virus (related to tobacco mosaic virus) is grown on different hosts. The most obvious change is the replacement of a lysine residue in the protein by a histidine residue when the virus grows on *Phaseolus vulgaris* as opposed to tobacco. A more detached study of this phenomenon is being undertaken, and is being supplemented by similar experiments using other viruses.

As an accompaniment to investigations on methods for isolating viruses, a study is being made of plant microsomes, which resemble viruses very much in their morphology and composition. There is, in fact, some indication that these normal constituents of leaves have on occasion been isolated and thought to be viruses. Because of this an investigation of ultracentrifugal isolation procedures is also under way, with the aim of establishing the reasons for, and the consequences of, the ultracentrifuge anomaly.

In addition to the more fundamental work carried out by the Unit considerable attention is paid to the maintenance of stocks of viruses of plants and of insects which are still under investigation, or which are used to provide material for chemical study. The Unit also undertakes the identification of a number of species sent in by various outside organisations, and supplies virus and other materials for scientific research as a courtesy.

HILL FARMING

HILL FARMING RESEARCH ORGANISATION

48, Palmerston Place, Edinburgh, 12

Director: A. R. Wannop, O.B.E., B.Sc.(Agr.), B.Eng., F.R.S.E.

ANIMAL STUDIES

Head of Department: J. F. Robinson,

B.Sc.(Agr.)

J. M. Doney, B.Sc., Ph.D.

J. N. Peart, B.Sc.(Agr.), M.Sc.

BOTANICAL STUDIES

Head of Department: R. F. Hunter,

B.Sc.(Agr.), Ph.D.

R. Hughes, B.Sc.(Agr.), M.Sc.

J. King, B.Sc.(Agr.), Ph.D.

I. A. Nicholson, B.Sc.(Agr.), M.Sc.

Secretary: R. S. Boyd

The Organisation exists to investigate methods of improving the agricultural output of hill land and the problems that arise in doing so.

At 31st March, 1959, the scientific and experimental staff of the Organisation numbered twenty-two.

CURRENT WORK

Animal Studies. Probably the most urgent problem in hill farming is the "hungry gap" period from January to April when nutritious hill herbage is at its lowest level of availability and hill ewes normally lose weight despite their advancing pregnancy. Supplementary feeding as a means of reducing the nutritional stress to which ewes are subjected during this period, has been investigated under hill conditions on the Organisation's three research stations for four years. The winter and spring of 1958-59 were mild, in contrast to those of 1957-58 and under the favourable weather conditions prevailing, supplementary feeding did not produce the beneficial results of the previous year. In one trial the response to an increase in the energy content of the supplement appears to confirm the indications of previous years that the deficiency in the ewe's normal diet at this period is as great in energy constituents as in protein. Where lamb crops are normally low, the results of supplementary feeding are satisfactory, but an apparent depression of production in certain circumstances needs investigation, and the long-term effects on ewes are still uncertain. Supplementary feeding on alternate days only is as satisfactory as daily feeding.

A trial at the Sourhope station in the Cheviot hills of mixed cattle and sheep grazing on a hill with an *Agrostis-Fescue* sward comprising one-third of the area and the remainder being *Molinia* and *Nardus*, has shown that over a seven-year period the annual increment of lambs, cast ewes and wool has increased by one-third and that the annual production of weaned calves equals in weight that of the sheep and wool sold. This beneficial effect of cattle is due primarily to a more effective utilisation of a herbage that sheep alone fail to graze effectively. In 1955, a mixed stocking was imposed on two further hill areas, and the results now being obtained confirm the beneficial effects of the older trial.

An analysis of past records for the Blackface flock at Glensaugh emphasises the drawbacks of selecting breeding animals larger than the fertility level of the hill can maintain. The ewe lambs retained for the

flock over a period of four years were grouped each year into Heavy, Medium and Light groups according to their weight in October of the year of selection. Though there was a slight narrowing of the differences in weight of the groups, a significant difference was maintained throughout flock life, there being a progressive increase in weight in all groups up to three years of age. In breeding performance, as measured by the percentage of lambs weaned during the first three lambs crops, the light group were slightly ahead of the medium group, which in turn was ahead of the heavy group. Weights of lambs at weaning were not significantly different between groups. The maintenance requirements of large framed animals appear to have a limiting effect on breeding performance under hill conditions, though this must be related to the nutritional level that can be maintained.

The other work of the department concerned with ewe hogg wintering, the influence of hormones on fattening wether lambs, lamb mortality, mineral metabolism and dentition, strain trials and selection for milk yield has been continued.

Botanical studies. Until recently, no herbicide was available which promised to be of value in hill pasture improvement. Now several grass and bracken herbicides have been developed, and these have been under examination. The grass herbicides appear to have two possible methods of use. Firstly, where they show selectivity, by selectively killing the less desirable species in a hill sward and secondly by killing all the grass species after which grass and clover seeds can be sown on the dead mat. On a plot scale Dalapon has proved successful as an aid to oversowing but it has to be ascertained whether the technique applicable on a plot scale can be applied over large areas, and whether reseedling by this method is suitable as a means of hill land improvement.

The practice of supplementary feeding of hill ewes in winter ought to be based on an understanding of the composition of their natural diet during this period and this problem is being studied by sampling the herbage. As is well known, one of the more intractable problems in pasture research lies in measuring the composition of the grazing animal's intake, as selective grazing results in an intake different from the average composition of the available grazing. Indeed, the development of methods of faecal analysis is the result of efforts to circumvent this problem and arrive at a solution by other means. The problem does not appear to be so difficult when dealing with hill pastures in winter as it is when lowland pasture in summer is being studied, as on the former, the range of choice and hence the degree of selectivity is greatly restricted. Methods of sampling have been developed to determine the range within which the composition of the diet should lie. It has been found that the limits of this range are sufficiently close to "bracket" the composition of the diet in winter with useful accuracy.

At the Organisation's research farm of Lephinmore in Argyllshire, a pasture improvement project is now under way on a hill enclosure of 100 acres. The general objective of the work is to find the extent to which a large area can be improved through increased stocking and fertility transference following the improvement of selected areas within it.

A preliminary year's observation has been commenced on the run-off from a peat catchment of approximately 20 acres. Detailed meteorological records have also been made and the relation between weather conditions and the amount and nature of run-off studied. It is intended, after the preliminary period of general characterisation, to surface-drain the bog, to subject it to various cultural treatments and to study their effects on the run-off.

The dry summer of 1959 has provided a useful opportunity to study the more extreme effects of drainage in peat soil, while vegetation changes induced by modifying the water regime are beginning to show clearly. The continuing work on the value of different species and grass strains for hill pasture improvement has demonstrated differences among these not evident in a more typical year.

The Organisation's work on muirburn, the value of different species and strains of grasses for pasture improvement and the ecology of the principal hill pasture species continues.

A fuller description of the work is given in the Organisation's First Report covering the period 1954-58.

ANIMAL BREEDING

A.R.C. ANIMAL BREEDING RESEARCH ORGANISATION

Headquarters: Glenbourne, South Oswald Road, Edinburgh, 9

Director: H. P. Donald, D.Sc., Ph.D., F.R.S.E.

Senior Scientific Staff:

N. Bateman, B.Sc., Ph.D.
H. B. Carter, B.V.Sc.
A. G. Dickinson, B.Sc., Ph.D.
J. G. Hall, Ph.D., M.R.C.V.S.
J. L. Hancock, M.V.Sc., Ph.D., M.R.C.V.S.
A. Jamieson, B.Sc., Ph.D.

J. W. B. King, M.A., Ph.D.
A. F. Purser, B.Sc., A.R.C.S.
St. C. S. Taylor, M.A., Ph.D.
J. H. Watson, B.Sc., Ph.D.
G. Wiener, B.Sc., Ph.D.
G. B. Young, Ph.D., M.R.C.V.S.

Livestock Officers:

*Pigs: G. R. H. Bishop, M.Sc., N.D.A.,
N.D.D.*

*Sheep: J. L. Read, B.Sc.
Cattle: D. Gibson, B.Sc., M.S., S.D.D.H.*

Secretary-Treasurer: F. H. James

The purpose of the Organisation is to acquire knowledge essential to the development by breeding of livestock of improved performance under both present and future husbandry conditions.

At 31st March, 1959, the scientific and experimental staff numbered fifty.

CURRENT WORK

Dairy Cattle. In view of the present interest in crossing dairy cattle, some observations made in the Organisation's herds may be mentioned. The main problems under study in these herds were referred to last year.

When Friesian cattle, which are large, are crossed with Jersey cattle, which are small, the size of the resulting calf at birth depends somewhat

on the breed of the dam. Genetically, the average calf should be the same whichever way the cross is made, but calves out of Friesian dams have been 8 lb. heavier than similar calves out of Jersey dams. In the Organisation's "crossing" herd, the Jersey dams produced large crossbred calves with no apparent difficulty even at a first calving. The two kinds of crossbred calf differed at birth in body dimensions as well as in weight, but for some dimensions the differences were small and for some they were large. It turns out that the former are those (e.g. length of head) that are relatively advanced in development, and the latter are those (e.g. width between hooks) that are relatively backward.

As the crossbreds grow to maturity, these distinctions are gradually lost. Both kinds of crossbreds show a conformation intermediate between those of the parents. This applies to each character separately. Consequently, a crossbred is not a sort of monstrous mosaic of parental features, but a beast with its own distinctive conformation. A Jersey x Friesian crossbred in fact is like neither parent in any of its parts. Its measurements happen to resemble closely those of an Ayrshire.

Under the conditions of the Organisation's dairy herds, calving in the months of April to August brings with it a reduction of about 100 gallons in lactation yield below that of autumn- and winter-calving cows. On many farms no doubt, young cows with poor yields are culled. Summer calvers are more likely to be culled for this reason. In these experimental herds no such culling is practised so it is possible to study the subsequent performance of the poor producers. On the whole, if they are really poor in one lactation they tend to be poor performers again. There are many exceptions of course, and much depends on the reason for a poor yield. If the reason is wholly or partly a spring calving, it will operate again the next year after a summer calving. A summer calving followed by an autumn calving works the other way and a considerably increased yield can be expected. There is a lesson in this perhaps for those who have to try to assess the breeding value of dairy bulls from the yields of their daughters. It may pay to give some thought to the dates of calving of those daughters.

The stage has been reached in the development of techniques for detecting blood groups in cattle at which practical applications would be possible if a service laboratory could be set up. Problems connected with the financing and staffing of such a laboratory are not readily solved, but efforts are being made by interested parties.

Sheep. The projects mentioned in last year's report are being continued but will not be specifically referred to now. Some other work has been going on in a variety of subjects. For a number of years half the ewe hoggets from our Blackface flock have been wintered at home and the other half wintered on low ground farms. The subsequent performance of these hoggets shows a favourable influence of away-wintering on fleece weights and body weights in the following year. This advantage fades out in time. At the levels of wintering studied, no aspect of reproductive performance seems to have been affected.

It is common knowledge that lambs of relatively low birth weight have a poor survival rate. In our flocks the very heavy ones have also shown a

poor rate. From a practical point of view, the important point is that there appears to be an optimum birth weight at which survival is at a maximum. This optimum turns out to be somewhat above the observed mean for our sheep.

An attempt has been made to see whether different breeds and crosses of sheep alter in relative merit when grown in different environments. This is a question of high significance in animal breeding and bears on the well-known problem whether or not it is a good thing to breed rams under very favourable conditions. In Britain, the distribution of breeds strongly suggests that the choice of an environment would markedly affect the outcome of a breed comparison. Factual evidence for this, however, is proving difficult to obtain.

In the Organisation's flock of 600 Welsh Mountain ewes, there were 113 lambs born to every 100 ewes put to the ram, but 14 of these died or were otherwise lost before weaning. Following persistent use of rams with non-hairy birthcoats over the past six seasons, the proportion of lambs like their sires in this respect has been increasing. At first the change was slow, but as the old ewes departed the rate of change speeded up. The sheep born with non-hairy birthcoats are now being compared with the normal type in survival and fleece characters. On present evidence, the former have a higher proportion of the better grades of fleece than the latter do.

Sheep have been found to differ in the kind of haemoglobin and in the amount of potassium in the blood, so the question arises why this variation persists—perhaps there is some advantage in it. The Organisation's sheep have been classified for both characters but so far no connection between blood character and ewe or lamb performance has been found.

New laboratories are being built and equipped for the study of fleeces, both on and off the sheep. They are intended to provide means of improving our knowledge of the way in which wool contributes to the well-being of sheep, particularly hill sheep, and our power to manipulate the factors influencing the quantity and quality produced.

Pigs. The testing of inbred lines of Large White pigs continues. The first comparisons of inbred lines and their crosses show no increase in litter size at birth as a result of crossing and the reduced litter size of inbred sows and gilts must therefore be attributed to a decrease in ovulation rate rather than to an increase in embryonic mortality. After birth the line-cross pigs do, however, show a marked improvement over the inbreds as regards both mortality and growth rates, although not on average surpassing the level of performance of outbred control pigs. The carcass quality of the crosses appears to be approximately intermediate between those of the parent lines.

Linecross and outbred control gilts are being saved for breeding in order to assess the litter performance of crossbred females.

Work on various aspects of artificial insemination of pigs has continued with special reference to the effect of intra-uterine as distinct from inter-cervical and intra-vaginal placing of semen in the sow. So far, the first method has been the most successful. Another aspect of great interest is presented by the fact that some fertilized eggs have more than the normal two pronuclei. If such eggs fail to develop, a contributory cause to low fertility may be revealed.

A.R.C. UNIT OF REPRODUCTIVE PHYSIOLOGY AND BIOCHEMISTRY

Molteno Institute of Biology and Parasitology and School of
Veterinary Medicine, University of Cambridge

Director: T. R. R. Mann, M.D., Sc.D., Ph.D., F.R.S.

Deputy Directors:

L. E. A. Rowson, O.B.E., M.R.C.V.S.
(Part-time)

A. Walton, B.Sc., Ph.D.

Senior Scientific Staff:

C. E. Adams, B.Sc., Ph.D.

J. C. Bournsnel, B.Sc., Ph.D., F.R.I.C.,
A.R.C.S.

E. F. Hartree, M.A., B.Sc., Ph.D.

E. J. C. Polge, B.Sc.(Agric.), Ph.D.

R. V. Short, Ph.D., M.R.C.V.S.

On 31st March, 1959, the scientific and experimental staff of the Unit numbered eight. Since the period covered by this report, the Unit has lost a particularly valuable member in the person of its Deputy Director, Dr. Arthur Walton, who died suddenly on 6th April, 1959, at the age of 62.

CURRENT WORK

The Unit engages at present in two types of research, (i) fundamental investigations on the physiology and biochemistry of reproductive processes, particularly in relation to the mammalian gametes, early stages of foetal development, and the mode of action of gonadal and pituitary hormones; and (ii) the application of newly acquired scientific knowledge to problems of animal breeding, such as the effect of nutrition on reproduction, transfer of ova, and the utilization of semen following prolonged (six years) periods of storage at very low temperatures.

The mechanism whereby nutrients, growth factors, and also certain toxic agents, pass from the body of the mother into the unimplanted or implanting embryo (blastocyst) is one of the most intriguing of the problems which confront the physiologist and biochemist investigating early pregnancy. The relationships which exist between the embryo and its environment were explored by methods involving the use of radioactive ions. Hormone treatment of the mother was found to cause profound modifications in the pattern of incorporation of radioactive ions into the embryo and the tissues with which it is associated. The development of a simple and rapid "flat-mount" method for histological examination of the rabbit blastocyst has made it possible to establish regions of differential sensitivity within the young embryo following treatment of the mother parenterally with certain cytotoxic substances. These were administered at dose levels harmless to the mother, and were capable of selectively destroying the embryonic disc, while leaving the cells of the trophoblast undamaged.

Chemical determinations of the actual concentrations at which hormones, and especially progestins, circulate in the blood of pregnant and non-pregnant animals, showed marked and hitherto unsuspected differences between the four main species of farm animals (mare, cow, ewe, sow). New findings were also made on the preparturition blood-level of progesterone and its derivatives, which tend to disprove some of the hitherto accepted views on hormonal mechanisms initiating parturition. Of two other studies pertaining to the physiology of pregnancy one has been directed at defining

the stage at which neonatal mortality is highest ; the other, arising out of an observation on the occurrence of free-martins in sheep, provided an indication that a state of tissue tolerance may exist between the free-martin and her male twin.

In the field of semen physiology and biochemistry one notable advance was the identification of sorbitol, the sugar-alcohol closely related to fructose, as a normal constituent of the seminal plasma (man, ram, bull, boar, stallion, rabbit). This was followed by the demonstration that sorbitol serves as a readily oxidizable nutrient substrate for spermatozoa and that the initial step in the metabolism of sorbitol by spermatozoa involves its oxidation to fructose, the latter being metabolized in due course to lactic acid. The sorbitol-oxidizing enzyme was successfully extracted from ram spermatozoa and purified to a considerable extent ; it was classified as a sorbitol dehydrogenase and is similar to an analogous enzyme in the liver. Further progress in semen biochemistry was made by the finding that the major intracellular lipid component of spermatozoa, identified in our earlier work as plasmalogen, participates actively in normal endogenous respiration of sperm. The motility of epididymal spermatozoa from different species (bull, ram, boar, stallion) induced by exposure to oxygen and contact with fructose was found to vary in a remarkable manner. This fact may possibly explain why diluents elaborated for the semen of one species often prove unsatisfactory when applied to the semen of other species.

A.R.C. UNIT OF ANIMAL GENETICS

Institute of Animal Genetics, University of Edinburgh

Honorary Director: Professor C. H. Waddington, C.B.E., M.A., SC.D.,
D.ÈS SC., F.R.S., F.R.S.E.

Deputy Director: D. S. Falconer, B.Sc., Ph.D.

ANIMAL BREEDING

A. Robertson, B.A., D.Sc.

I. L. Mason, B.A.

G. A. Clayton, B.Sc., Ph.D., Dip.An.Gen.

MAMMALIAN GAMETES

R. A. Beatty, M.A., Ph.D.

MOUSE GENETICS

D. S. Falconer, B.Sc., Ph.D.

DROSOPHILA GENETICS

E. C. R. Reeve, B.A., Ph.D.

F. W. Robertson, D.Sc., Ph.D.

On 31st March, 1959, the scientific and experimental staff numbered fourteen.

The aims of the Unit are: (a) to carry out operation research on the livestock industry ; and (b) to study those aspects of genetics and developmental physiology which seem likely to be particularly relevant to our fundamental understanding of animal breeding problems.

CURRENT WORK

Animal Breeding. Work is proceeding on the progeny testing of Friesians for beef production, and on the breeding programme of the A.I. centre in Cambridge. The use of the contemporary comparison method for evaluating progeny tests for yield has been further supported by the finding of a good positive correlation between tests on fathers and their sons. The

relative rankings of A.I. bulls with daughters in many herds at different production levels has shown that there is good agreement between progeny tests at high and low levels, so that there is no necessity in this country to use different sires at the different levels.

Co-operative work with Dr. Neimann-Sørensen in Denmark has shown that it is unlikely that the genes controlling blood-groups account for much of the observed variation in quantitative characters, although they may contribute a small amount (up to 5 per cent) to variation in fat content.

A paper has been published on the effect of light during rearing on the egg laying of turkey hens. Data are now accumulating on the heritability of egg production and body weight, and work is continuing on the development of different breeding plans.

Theoretical studies have included the design of experiments for the estimating of genetic parameters and their sampling variances, the role of chance fixation in selection, the use of selection limits as a means of studying quantitative variation, etc.

Mammalian Gametes. Investigation has continued of the existence and magnitude of genetically controlled variation in the gametes of mice and rabbits. An extensive series of comparison of a number of dimensions of the sperm of inbred strains of mice and their crosses has shown that in several cases the strains are significantly different. In crosses evidence for "heterosis" has been found—an unexpected and perhaps very important fact where haploid cells are in question. Studies are in progress on the effect of certain single genes, particularly those involved in the determination of coat colour, on structural and biochemical characteristics of the sperm.

Mouse Genetics. Most of the work with mice has been concerned with the long-term effects of selection for quantitative characters. Selection for body size—both large and small—started in 1947, has reached the 52nd generation and progress has ceased. Selection for high and low fertility (litter size) has reached the 30th generation. There has been slow but erratic progress in both directions and the difference now amounts to about $2\frac{1}{2}$ mice per litter. An experiment on selection for growth rate on high and low planes of nutrition has been terminated. Selection on low plane produced the more "economically desirable" animals: they grew better on low plane and nearly as well on high plane, and they were less fat. In an experiment designed to compare the results of selection for weight at different ages, in connection particularly with the fatness of the carcass at 6 weeks, it was found, contrary to expectation, that selection at 3 weeks produced fatter mice than selection at 6 weeks. The efficacy of "reciprocal recurrent selection" as a means of increasing the body size of cross-bred mice is being tested. No new work has been started recently, in expectation of a move into a new animal house.

Drosophila Genetics. Gene-environment interaction in the growth of *Drosophila* is being studied with the aid of chemically defined media, to determine its properties and relative importance for different characters in different genetic situations, to see how far parallel selection in different conditions involves physiologically distinct changes and also to clarify genetic aspects of the regulation of body size and other attributes.

Current experiments are designed to arrive at a quantitative relation between X-ray dosage and the level of new genetic variation which can be detected in various quantitative characters in *Drosophila*. The procedure eliminates the effects of heterozygous recessive lethals and should provide evidence on controversial claims about the intrinsic properties of heterozygotes.

The inheritance of the capacity to respond adaptively to an environmental stress has been further studied by rearing *Drosophila* larvae on media containing just sub-lethal quantities of sodium chloride. After some twenty generations during which natural selection was strongly operative, a strain had been produced in which the capacity to adapt to the salt had been improved, and the general level of the response, at all concentrations, had been raised.

Work continues on the estimation of the rate at which X-rays induce new variation in a quantitative character (bristle number), and the same character is also being used for studies on the rate of response to selection using progeny testing and assortative mating.

ANIMAL DISEASES

A.R.C. FIELD STATION

Compton, Newbury, Berks.

Director: W. S. Gordon, C.B.E., Ph.D., M.R.C.V.S., F.R.S.E.

Deputy Director: H. H. Holman, D.Sc., Ph.D., F.R.C.V.S.

BACTERIOLOGY

Head of Department: S. J. Edwards,
D.Sc., F.R.C.V.S.

A. McDiarmid, D.Sc., Ph.D., M.R.C.V.S.,
F.R.S.E.

J. D. Rankin, Ph.D., M.R.C.V.S.

R. L. Chandler, B.Sc., Ph.D., F.R.C.V.S.

J. M. Payne, B.Sc., Ph.D., M.R.C.V.S.

PATHOLOGY

Head of Department: I. H. Pattison,
B.Sc., M.R.C.V.S.

W. J. Hadlow, D.V.M. (Seconded from
U.S. Department of Agriculture)

C. D. Bracewell, B.Sc., B.V.Sc., M.R.C.V.S.

A. Mackenzie, M.R.C.V.S.

RADIOBIOLOGY

Head of Department: R. J. Garner, M.A.,
M.V.Sc., F.R.C.V.S., A.R.I.C.

H. G. Jones, B.Sc., Ph.D.
(Seconded from M.R.C.)

ANIMAL ECOLOGY

Head of Department: A. Brownlee,
B.Sc., M.R.C.V.S.

FARMS

Manager: E. V. Knight, O.B.E., B.Sc., N.D.A.

Secretary: F. R. Meakins

ISOLATION COMPOUND

Manager: J. Elliot, M.A. (Agric.)

The Council's Field Station at Compton has the function of studying certain diseases of farm animals. It is an estate of 2,000 acres which is farmed intensively to produce feeding stuffs and animals of known health history so that a flow of suitable cattle, sheep, pigs, goats and small laboratory animals from the Station's normal breeding herds can be provided for experiments.

At 31st March, 1959, the scientific and experimental staff of the Station numbered twenty-five.

CURRENT WORK

Contagious Bovine Abortion (Brucellosis). It was previously reported that an effective immunity had been produced in cattle by two injections of a dead vaccine prepared from *Brucella abortus*, strain 45/20. This vaccine does not produce agglutinins but, because of a severe local reaction at the site of injection, it could not be recommended for general use. The irritant substance in the vaccine was found to be the adjuvant "Falba". A number of different adjuvants prepared by Glaxo Laboratories Ltd. have been tested in cattle and the least irritant selected for vaccine making. Immunity tests of this new adjuvant vaccine are in progress in mice and guinea pigs and, if successful, these will be followed by large-scale tests in cattle.

The eradication of Brucellosis is an interesting possibility and, to assess the extent of the problem in a circumscribed area, a working group of medical, veterinary and sanitary personnel, centred on Compton, has been formed. The purpose of this group is to determine the incidence of the disease in man and cattle in the district, and to study the means whereby it may be further reduced. Already the majority of infected farms in Oxfordshire have been located; large numbers of human tonsils, after removal, and placentae from patients positive to the agglutination test are being examined for the presence of *Brucella abortus*. This survey will provide useful information on the nature of the eradication problem.

A preliminary study of the pathogenesis of *Br. abortus* infection in the rat has been followed by an intensive study of the progress of infection in the cow. In the pregnant cow it was found that the organism, after first localising in lymph nodes nearest the point of entry, then spread both to lymphoid tissue elsewhere and to the gravid uterus, which was entered by way of the endometrium and uterine glands. In non-pregnant cows also *Br. abortus* was localised in lymph nodes near the point of entry but the infection regressed without affecting the uterus. Further work is being carried out to try to discover the factors necessary for uterine infection, including a study of the infection of cows receiving continuous treatment with progesterone.

In the course of experiments with Brucellosis infection in rats, the placenta was found to be particularly vulnerable to infection. It has also been found that the placentae of pregnant rats can be experimentally infected with a variety of bacteria and viruses which may not produce a progressive infection in non-pregnant animals. This suggests that the pregnant rat may be a more useful research tool than the non-pregnant animal in the study of some infectious diseases. In current work, pregnant rats are being used to assess the importance of local immunity in the prevention of placental infection.

It has been found that autogenous grafts of certain parts of the rat placenta on to the omentum are liable to develop into teratoma-like cysts. Skin, cartilage, hair, bone, muscle and mucous secreting epithelium frequently appear side by side in the same graft. As the implications of this finding may be important the genesis and hormone dependence of these structures is being investigated.

Mastitis in Cows. A survey of the phage types of staphylococci, isolated from cows at the Field Station that become affected with mastitis, and the

possible correlation of phage type with epidemiology and susceptibility to antibiotic treatment is being made. Observations on the use of antibiotics for the prevention of summer mastitis are being continued.

Studies in immunity to staphylococcal mastitis are proceeding and the protective effect of vaccination with an adjuvant cell-toxoid prepared from *Staph. aureus*, strain 201, against a massive experimental mammary infection with the homologous strain, has now been demonstrated in cows. Experimental testing in goats of the components of this vaccine has shown that protection is only given by those vaccines that contain toxoid. It has also been shown that the vaccine prepared from strain 201 possesses little power to protect goats against infections with some other strains of staphylococci. Experiments are in progress to determine whether this difference is due to toxins of different antigenic type, or to other pathogenic properties of the organism against which an adjuvant cell-toxoid vaccine fails to protect.

Johne's Disease. Experiments started last year in the estimation of oral doses of *M. johnei* suitable for infecting calves are being continued, and work on the pathogenesis and propagation of the organism in calves following infection by the oral route has been commenced. Infection experiments in mice, rats and rabbits are being continued.

Complement-fixation tests are again being carried out on the cattle on the Field Station's farms, this time with the object of following the test histories of the cattle from birth upwards. Studies on modified vaccines are being carried out in an attempt to find a protective vaccine that will not sensitise cattle to tuberculin.

Scrapie. Sheep from twenty-four different breeds have been tested for susceptibility to scrapie. Using the same inoculum throughout, the incidence of experimental infection over a two-year period of observation varied from no affected sheep in one breed, to 70 per cent infection in the most heavily infected breed. Different families within a breed also showed differences in susceptibility as great as that between breeds. It has been found that the progeny of parents inoculated with scrapie-carrying tissues may develop scrapie. Experiments are in progress to try to confirm this observation, and to examine the mechanism of transmission through sire and dam to offspring. It is planned to develop, by selected matings, scrapie-susceptible and scrapie-resistant lines.

Further experimental inoculations of goats have confirmed the high percentage "take" in this species when inoculated intracerebrally. Taking advantage of this susceptibility, experiments are in progress to find the distribution of the infective agent in different body tissues, at different times during the course of the disease, and also to discover something of the nature of the causal agent.

In order to gain a better understanding of the pathology of scrapie, a detailed study of the disease induced experimentally in goats is being made. It has been found that significant morphological changes were present only in the central nervous system, and that these alterations consist of widespread neuronal degeneration and variable, but usually pronounced, astrocytic hypertrophy. Although this study is incomplete, the topographical distribution of the lesions, which are bilaterally symmetrical, would seem

to be in many respects consistent with the clinical signs observed in the goat, suggesting that scrapie is a progressive degenerative disorder of the central nervous system.

Polled Ayrshire Breeding Experiment. This long term project is progressing in accordance with the plan outlined in the previous report. At the end of March, 1959, two young heterozygous polled bulls of the third backcross generation FR₃ began to serve pedigree Ayrshire females. The first FR₄ (fourth backcross) offspring may therefore be expected early in 1960.

Experiments are in progress to determine if there is any linkage between any of the numerous blood group genes and those determining the polled, or horned, characters. This work is being done in collaboration with Dr. Jan Rendel of the Institute of Animal Breeding, Royal Agricultural College of Sweden, Uppsala. Blood samples from cattle in the various categories are being tested both by Dr. Rendel with his reagents and at Compton using the reagents provided by Dr. J. Hall of the Animal Breeding Research Organisation, and by additional reagents prepared at this Field Station. Apart from the fundamental interest of this study, any positive results might prove very helpful in the diagnosis of homozygosity for the polled character in both sexes.

Animal Ecology. Continuing the study of the effect of diet on the stomach of the rat, the bacterial flora of this organ was investigated. With rats fed on a mash diet it was found that the non-glandular area contained large numbers of aciduric gram positive bacilli. If the mash was given *ad lib.* the bacilli were often present in chains and long filaments, but where rats were trained to eat a large amount of mash in a short time, the films showed large numbers of short forms, and chains or filaments were scarce. It was found that these bacilli disappeared entirely, or almost entirely, when rats were fed on a flesh diet.

Clinical Pathology. Routine biological tests are carried out on the normal breeding herds and flocks, and diseases occurring spontaneously in these animals receive clinical attention and investigation. Laboratory investigations are made on the more problematic diseases. These have included a rapidly fatal jaundice of housed sheep, associated with high liver copper storage, and an encephalitis associated with the presence of *Listeria monocytogenes* which occurred in purchased sheep. Other infectious diseases encountered in sheep and goats purchased from outside sources included vibronic abortion, contagious pustular dermatitis, Johne's disease and coccidiosis.

Pneumonia in Pigs. The pathology of pneumonia in pigs caused by an haemophilus-like organism was examined in detail, and it was demonstrated that changes similar to the pneumonia and pleurisy present in naturally infected pigs were produced by inoculation of normal pigs with pure cultures of the organism. The investigation showed that the nodular type of pneumonia, seen in the active phase of the disease, is succeeded by a chronic phase that consists of simple fibrous pleurisy alone. The organism responsible has now been identified as *Haemophilus para-influenzae* on the basis of its growth requirements, but it is a different serological type from the human strains of *H. para-influenzae* that have been examined.

Work is in progress to establish if the high incidence of localized chronic pleurisy, which affects up to about 30 per cent of bacon pigs in some herds, can be attributed to this type of infection and an assessment of its effect on growth rate and food conversion is being made. Preliminary work on the serology of this and other pneumonic conditions in pigs is in progress.

Radiobiology. A systematic study of the radiotoxicity of fission products to the dairy cow has been initiated with work on the toxicity of ^{131}I , and the hazard to the gut from insoluble isotopes. It is hoped that experiments with ^{144}Ce and ^{95}Zr will yield results of fundamental importance concerning the physiology of the gut in ruminants.

The metabolism of the alkaline earth elements, calcium, strontium and barium, has been examined in detail. Intestinal absorption has been found to be the major process involved in discrimination between the three elements during their transfer from the diet of a cow to its milk, and it has been shown that barium is concentrated in the uveal tract in herbivores.

Work on the transfer of fission products from the diet to the milk, in cattle, is continuing and will be extended to cover alpha emitters such as plutonium.

Haematology. Measurements on the blood picture of the goat have been continued for a second year. Haematological measurements have been carried out for other departments and the work on blood grouping is reported under the Polled Ayrshire Breeding Experiment.

FOOT-AND-MOUTH DISEASE RESEARCH INSTITUTE (Animal Virus Diseases)

Pirbright, Surrey

(World Reference Laboratory for Foot-and-Mouth Disease)

Director: Ian A. Galloway, D.Sc., M.R.C.V.S.

Deputy Director: J. B. Brooksby, D.Sc., Ph.D., M.R.C.V.S.

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Inactivated Vaccines: N. St. G. Hyslop,
B.V.Sc., M.R.C.V.S., D.T.V.M.
A. W. Morrow, M.A., B.Sc.
G. N. Mowat, M.R.C.V.S.
Miss S. F. Cartwright, B.Sc.
Mrs. J. O. Farley, B.Sc.

Live Vaccines (modified strains):
H. H. Skinner, M.R.C.V.S.
K. J. O'Reilly, B.Sc., M.R.C.V.S.
Miss W. P. Heatley, M.Sc.

SEROLOGY

J. Davie, B.Sc., M.R.C.V.S.
Miss J. Delf, B.Sc.

TISSUE CULTURE

W. B. Martin, M.R.C.V.S., D.V.S.M.
E. B. Davies, B.V.Sc., M.R.C.V.S.
Miss D. L. Stewart, B.Sc.

PATHOLOGY AND EXPERIMENTAL CYTOLOGY

H. Platt, Ph.D., M.V.Sc., M.R.C.V.S.

GENETICS

H. S. Sharpe, B.Sc., Ph.D.

BIOCHEMISTRY

F. Brown, M.Sc., Ph.D.
Miss J. Crick, M.Sc.

BIOPHYSICS

C. J. Bradish, B.Sc., Ph.D., A.Inst.P.
H. V. Thorne, B.Sc., Ph.D., A.R.C.S.

DISEASE SECURITY OFFICER

H. Cronly, C.B.E., M.R.C.V.S.,
D.V.S.M., D.T.V.M.

Secretary: A. C. T. Edwards, C.B.E., B.A.

At 31st March, 1959, the scientific and experimental staff of the Institute numbered thirty-three.

CURRENT WORK

Epidemiological Surveys and Immunological Typing of Virus Strains. Since the establishment of the World Reference Laboratory in July, 1958, over 867 samples from 27 countries other than Great Britain have been examined. The use of kidney tissue cultures for typing has been investigated and by suitable manipulations an answer to the type of virus involved in any outbreak can be obtained within 48 hours of receipt of the field samples. This represents a considerable acceleration in the obtaining of results over that using baby mice. Moreover positive results have increased from 60 per cent to 80 per cent.

Recent information of interest is that there has been a widespread outbreak of foot-and-mouth disease in South Africa and the type of virus involved has been confirmed as S.A.T.3. This is the first time this has been associated with outbreaks in South Africa and it has been demonstrated in field samples from wild game e.g. impala, as well as cattle and also from cattle in Mozambique across the border.

Type Asia 1 virus has been found in Syria.

Live Vaccines. Brief reference was made in the last report to work which has been proceeding at the Institute for several years now on the modification of strains of virus with a view to reducing their infectivity for cattle to a point when they could be used as live vaccine. Attenuation of the various strains of the virus has been achieved by serial passage in baby mice, in older mice or in chick embryos. Whatever method has been used for modifying the virus there has been a progressive reduction in infectivity for cattle. When the strains reached an appropriate degree of attenuation, the immunizing properties of these have been tested and about a thousand cattle have been used in these investigations. The very encouraging results obtained up to April, 1959, were reported at the International Veterinary Congress in Madrid in May. The work is still continuing and it is a long term project. Much still requires to be done in the study of such aspects as the stability of these live vaccines on storage under different conditions, methods of improving their immunising properties, the duration of immunity in animals injected with them, the development of methods of bulk production and polyvalent vaccination.

In addition to the experiments carried out at Pirbright with these live modified strains, mainly on cattle about 18 months old, but also on some 4-month old calves, several small scale experiments have already been carried out in East Africa and in Thailand with three different modified strains and a study of duration of immunity is in progress. It is necessary to know the effects of the inoculation of these live attenuated strains and assess their immunising properties in cattle in endemic areas where there are animals of different breeds, grade cattle and indigenous stock and animals which differ from those used at Pirbright in that they may not have a clean history in respect of previous exposure to infection with the virus.

Many more experiments will have to be done on other animals and with different modified strains at Pirbright and in these regions before all the necessary information is obtained. Polyvalent vaccination is the ultimate aim and this is a problem calling for additional trials.

Genetics. Special mention may be made of studies on the relative sensitivities of seven different strains of mice which when inoculated intraperitoneally or intramuscularly are in the same order but not always apparently of the same magnitude. The intramuscular route is always more sensitive than the intraperitoneal route but the magnitude of the difference depends on the virus strain and varies from two to sixteen times.

Two new strains of mice of higher sensitivity than the P strain which has been in current use, have been evolved, one of which is going to be produced in large numbers.

The economical use of mice in experiments has been investigated and graphs have been made generally available to other members of the staff. These allow planning of experiments to obtain the maximum information from the available mice using special experimental designs.

Pathology and Experimental Cytology. Experiments on the localisation of lesions in guinea-pigs have been continued. It is concluded that susceptibility to the virus depends on some properties of the epithelial cells themselves and is in some way related to the hyperplastic condition of epithelium subjected to persistent irritation. The mechanism may probably be related to modification of the cell metabolism or of the surface properties of the cell.

Other experiments have been carried out on the effect of strain differences of the host on susceptibility. Some adult mice of a highly susceptible strain were found to develop severe pancreatic lesions following infection with foot-and-mouth disease and the virus was recovered from the pancreatic tissue in high concentration.

Agar Gel Diffusion. It has been shown by immuno-electrophoresis that the precipitating antibody present in ox serum early in convalescence has a mobility in an electric field markedly different from that in serum taken later in convalescence. This difference can also be detected by the behaviour of the sera on ion exchange resins.

Infective Ribonucleic Acid. The work referred to in the last report has been continued. It has been found that small amounts of proflavine added to a tissue culture which has been infected with the virus of foot-and-mouth disease inhibits the formation of complete virus although the yield of ribonucleic acid (RNA) is not diminished. This has given a method of separating the two processes of RNA synthesis and virus synthesis and the work is being extended to the use of other blocking agents.

Freeze Drying of Virus and Vaccines. Suspensions of the virus of foot-and-mouth disease can now be dried with subsequent complete recovery of infectivity if the drying is carried out in the presence of sodium glutamate. Similarly inactivated virus vaccines can be dried under the same conditions without loss of immunogenicity or ability to precipitate with the homotypic antiserum in agar gel diffusion tests.

Virus Aerosols. A satisfactory method of sampling virus aerosols has been found by employing the Porton type of impinger. The penetration of virus through various materials of possible value in the filtering of air from virus contaminated areas has been investigated. A glass fibre paper was found to allow only very low penetration of the virus.

Skim Milk. The Animal Health Division of the Ministry of Agriculture, Fisheries and Food sought advice on the possibility of inactivating by acidification the virus of foot-and-mouth disease in skim milk, the distribution of which for feeding animals, if untreated, can be a means of disseminating the disease. It was found that acidification of artificially infected skim milk to pH 5.05 and pH 5.5 for 20 hours rendered the product non-infective for unweaned mice inoculated with it. However in two tests in which cattle were inoculated with similarly treated milk evidence of some virus survival was obtained; 10 of 12 cattle inoculated intradermally into the tongue developed lesions at some of the sites of inoculation. It is considered that although treatment of milk in this manner would have been a relatively simple procedure if effective in a one-stage process, it would not be a satisfactory or practicable method for application in the milk industry.

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CLINICAL INVESTIGATION

C. C. Renwick, M.R.C.V.S., D.T.V.M.

Secretary: D. M. Cameron, A.C.I.S.

The work of the Institute is to investigate the etiological factors concerned with diseases of farm animals and to discover means of preventing such diseases.

The scientific and experimental staff at 31st March, 1959, numbered twenty-nine.

CURRENT WORK

Johne's Disease. The host-parasite relationship of mice, guinea pigs and lambs after intravenous infection with *Mycobacterium johnei* has been studied by quantitative bacterial counts of the tissues and vaccinated and non-protected animals have been used to assess the value of antigens which may protect against the experimentally induced disease. The difficult technical problems associated with such methods have been overcome and replicate experiments have shown very satisfactory correlation over the last year. For example, it has been established that tissue count differences

of 30 per cent. between treatments were significant and this degree of accuracy has stimulated further research.

Although it has been established that some vaccines do assist animals to overcome the experimentally induced disease, the character of the resistance and the application of the results to natural infection require to be determined. Experiments have shown that after parenteral infection certain body organs and tissues of laboratory animals offer an unsuitable environment for multiplication of *M. johnei* and this applies also to sheep which are truly susceptible to natural infection.

Work on the host-parasite relationship in the different tissues of animals is now in progress and on the pathogenesis of Johne's disease. These studies appear essential before control of the natural disease and the carrier state can be contemplated further.

Sheep Pneumonia. Pathogenicity experiments in young lambs have shown beyond reasonable doubt that *Pasteurella haemolytica* is the organism which causes septicaemia in sheep. It has been established experimentally that small numbers of this organism can produce a fatal disease in lambs with several features similar to those of the natural disease. Two types of the organism have been described, Type A from pneumonia and Type T from sheep septicaemias. A considerable number of these strains has been isolated and examined antigenically and it has been found that most T type organisms are related but that none of the A types give protection to mice against challenge with one of the T strains. The recent finding of Type A organisms in septicaemias of very young lambs is in contrast with the previously observed correlation of Type T strains with septicaemia of older sheep.

Scrapie. Investigation of the scrapie agent includes microscopy, tissue culture, and biochemical techniques of purification. The product of a preliminary procedure involving salt fractionation and centrifugation of infected brain material appeared to be fairly successful in producing the disease in experimental sheep. Various studies of changes in blood proteins and a survey of phenotypes involved in susceptible sheep have been made. Further findings in the controlled breeding experiment confirm that there is a very high correlation in incidence of scrapie between mother and offspring. Histological studies on tissues from scrapie sheep have shown that there is degeneration and vacuolation of neurones in the spinal cord as well as in the brain where certain cell groups are invariably affected. The lesions in the cord are mainly in the intermediate zone which contains nerve cells interposed between the incoming dorsal root fibres and those descending from the higher centres and the motor nuclei. Completed work on skeletal muscle has shown that myopathy is not a characteristic lesion of scrapie.

Hypomagnesaemia. Further studies were made of factors which may influence the magnesium status of sheep and cattle. These included the availability of the magnesium in the diet, changes in the nature of the diet and the fertiliser treatment of spring pasture. Experiments with Mg^{28} showed that the isotope could be assayed in the urine and faeces of sheep for four to five days after intravenous or ruminal administration. The values obtained for the endogenous faecal loss of magnesium and the availability of magnesium in the diet confirmed those obtained previously by indirect methods.

A study to obtain information on the mineral composition of spring pastures associated with lactation tetany and hypomagnesaemia in dairy cows has been initiated in collaboration with the East and West of Scotland Agricultural Colleges.

Osteodystrophic Diseases of Sheep. The pathology and chemistry of this diverse group of conditions is being fully investigated. By this means it is hoped to classify the numerous bone diseases of sheep.

Parasites and Parasitic Diseases. An attempt was made to raise 100 lambs on the bottle by the method of weaning abruptly at one month but the animals were found to require more individual attention than they could be given. The weaning procedure was, therefore, modified for the majority from whom milk was gradually withdrawn between the ages of one and two months. This proved successful and less than 10 per cent. loss has been sustained during the first four months of life. The bulk of this worm-free stock is to be used for an experiment to study the development of resistance and possible self-cure in groups receiving daily doses of infective larvae at three different dosage levels.

A further experiment on the spring-rise of egg output after parturition in housed animals was carried out on a larger group of animals. This fully confirmed the earlier result. In spite of a rigorous exclusion of larval challenge, a very marked increase in egg output occurred and this was accompanied by a significant concurrent fall in haematocrit levels.

In a preliminary experiment on the effect of various factors on resistance to helminths no significant change was found in the faecal worm count of febrile sheep experimentally infected with tick-borne fever.

Work has been started on resistance to helminths using *Nippostrongylus muris* infestation of rats but has been concerned hitherto mainly with the technical problems of culturing the parasite and with methods of transferring known numbers of viable intestinal stages from one host to another.

The technical problems of collecting eggs of *Nematodirus battus* free from debris have been so successfully solved that it is now possible to obtain high recoveries from faeces in bedding thus permitting the use of ewe lambs for stock production of this worm. Upwards of 80 per cent. infective larvae can be obtained from ripe eggs by a mechanical hatching method for stock purposes and for use in *in vitro* culture work. The development dynamics and hatching mechanism of this species are at present being studied.

Earlier success using the Weinstein and Jones roller tube method for *in vitro* culture of parasitic stages has been found too inconstant for the practical production of parasitic forms and their associated antigens. A search for improved nutritive substrates has been temporarily abandoned and a closer study is being made of the physical conditions required for maintenance of larval populations with predictable mortalities. In the course of this work a significant proportion of larvae has performed the first parasitic moult in a medium whose sole nutrient is glucose. This promises a possible method for producing uncontaminated antigens. Part of the variability in mortality has been presumed to be due to the use of "chemical means" (hypochlorite) to produce exsheathment of third stage larvae. An alternative "physiological method" has been discovered in the course of a wider study of the exsheathment process in *Haemonchus contortus*. The

method also permits of collection of uncontaminated moulting fluid for future serological work.

No evidence has been found of any direct action of Aphodiid beetles on work larvae in dung but two Staphylinids have been observed searching for and feeding on *H. contortus* larvae on the surface of pellets. In one experiment 98 per cent of migrating third-stage larvae were destroyed in 24 hours by adult *Atheta atramentaria*.

In the pilot experiments started last year with experimental single species infestations in the field, the *N. battus* infestation has been built to a significant level by two animals infested by the initial residuum from four years ago. The *H. contortus* population has shown a negligible winter carry-over from the previous August, a result contrary to earlier findings with plant-pot infestations.

ANIMAL PHYSIOLOGY AND NUTRITION

THE ROWETT RESEARCH INSTITUTE

Bucksburn, Aberdeen

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Deputy Director: A. T. Phillipson, M.A., Ph.D., D.V.Sc., M.R.C.V.S., F.R.S.E.

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A. Dobson, B.A., Ph.D.
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Secretary: W. Middleton, N.D.A.

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Head of Department: A. W. Boyne, B.Sc.
I. McDonald, M.A.

DUTHIE EXPERIMENTAL STOCK FARM
W. Thomson

Librarian: W. L. Simpson, M.A.

The work of the Institute is directed to an understanding of the energy and material requirements of animals of agricultural importance. A study is also made of the relationship of diet to metabolic disorders and other underlying causes of susceptibility to disease. On the basis of the new knowledge obtained and of researches elsewhere, exploration is made of the best systems of feeding livestock and of the influence of environment on their utilisation. Man's food requirements are also kept under review. The Commonwealth Bureau of Animal Nutrition is located at the Institute.

The scientific and experimental officer staff of the Institute at 31st March, 1959, numbered ninety.

CURRENT WORK

Protein and Lipid Chemistry. The protein metabolism of ruminants has been studied in relation to dietary lipids by artificial rumen techniques and in relation to energy sources in different parts of the alimentary canal. A cannula has been developed for obtaining samples of ingesta flowing out of the rumen which should be useful in a number of investigations.

Work on the greenleaf has related to the larger peptides, to plastid and cytoplasmic proteins and to enzymes associated with protein degradation in wilting.

The Lipid Section has been concerned with the intestinal absorption of vitamin E in pigs, the digestion of glycerides in the rumen of sheep and the role of blood lipids in bovine milk fat formation.

Microbiology. A relationship has been shown to exist between certain types of bacteria, the presence or absence of protozoa and the diet of early weaned calves; and the study of conditions necessary for multiplication of protozoa in young animals has been extended. Studies on the carbohydrate metabolism of the holotrich protozoa were completed and the carbohydrate metabolism of the smaller oligotrich protozoa is now being investigated. The pentosan-degrading enzyme systems of two types of rumen bacteria grown in pure culture have been characterised and compared, and isolation of other hemicellulose-degrading bacteria is proceeding. More extended observations have been made on the occurrence of a large lactate-utilising coccus in young and old animals, and possible reasons for its changing numbers in the rumen have been tested. Using this organism attempts have been made to change the rumen flora by inoculation, but from all the results it appears that the rumen flora is extremely stable under any one feeding regime.

The investigation of proteolysis in the rumen has continued with *in vitro* measurements of the proteolytic activity of different fractions of rumen contents, and *in vivo* determinations of the changes in proteolytic activity and the redistribution of food protein nitrogen at intervals after feeding. These experiments have shown that proteolytic activity is found amongst all types of rumen organisms and at all times of day and a rapid breakdown of foodstuff protein occurs in the rumen. Attempts to isolate actively proteolytic bacteria have been partially successful.

Investigations in collaboration with the Lipid Chemistry Section have shown that extensive hydrolysis of foodstuff lipids takes place in the rumen *in vivo* and in rumen contents *in vitro*, and the isolation of bacteria that utilise oil and glycerol is now in progress, so that a more detailed study of these reactions can be made.

A short term manometric method of investigating rumen metabolism has been developed and is being applied to experiments on antibiotic-fed calves.

Enzymology. In earlier work, it was shown that the male and female genital tract, in particular the epididymis, is rich in β -galactosidase, α -mannosidase and β -N-acetylglucosaminidase activity; these enzymes are present in all mammalian tissues and their activity is under endocrine control. They probably participate in the catabolism of mucopolysaccharides.

An effort is being made to find whereabouts these enzymes are located in the cells of the liver: they appear to be situated in the cytoplasmic granules (microsomes and mitochondria). Their activity in the wall and the lumen of the alimentary canal is appreciable throughout its length. The kinetics of action of β -galactosidase and α -mannosidase have been studied, and previously reported data for β -*N*-acetylglucosaminidase confirmed. Pig epididymis has been shown to be an enormously rich source of β -*N*-acetylglucosaminidase, and considerable progress has been made in purifying the enzyme.

A stable cadmium iodide-starch reagent has been used to estimate chromate or dichromate. The previously developed micro-method for the colorimetric determination of cellulose has thereby been greatly improved, and quantities of the order of 10 μ g. carbohydrate (or protein) may now be accurately determined. The procedure would enable the measurement of the organic content of waste liquors or sewage, or of biological concentrations (e.g. 0.1 g./ml.) of chromium. The method is being employed to study the kinetics of enzyme attack on phosphoric acid-treated cellulose by cell-free filtrates from *Myrothecium verrucaria*.

Studies of the anaerobic breakdown of native cellulose by micro-organisms of the sheep's rumen continue; acetone-treated preparations of these bring cellulose into solution but this is due to survival of certain stable organisms which, however, require strict anaerobiosis for growth or cellulolytic activity. It is hoped to obtain pure cultures of these organisms for further investigation.

Physiology. Factors influencing the secretion of saliva and gastric juice of sheep have received further attention. The diffusion of calcium and magnesium in the normal alimentary contents of sheep has been studied using membranes of known pore size. The sodium, potassium and water balance of sheep of two blood cell types maintained under temperature-controlled conditions has been determined and groups of lambs of different red cell type have been bred for future work. Preliminary work on the larger direct calorimeter indicates that its performance is satisfactory. A technique for quantitative studies of the metabolism of isotopically labelled fatty acids by the liver "in situ" is being developed and further studies of the assimilation of ammonia nitrogen by rumen bacteria have been made. The rate of disappearance of food from the rumen of sheep is under investigation by comparing the results obtained with two markers against the results obtained using an emptying technique.

Director's Unit. The effect on foetal growth of various levels of the antimetabolite aminopterin, given to pregnant rats has been studied at various dates of gestation.

The effect of injury has been studied in the ruminant. The urinary nitrogen response is similar to other species. The basal metabolic rate, using a direct calorimetry method, has also been studied on male rats maintained on diets varying in caloric and protein content.

The investigation of the metabolism of strontium-89 and calcium-45 in sheep is continuing. A diet deficient in calcium and phosphorus is being compared with one containing adequate amount of these elements in its effect on the metabolism of ^{89}Sr and ^{45}Ca in pregnant and lactating ewes.

Pathology. Work on the factors in normal and immune sera responsible for the inhibition of bacterial growth in embryonated eggs experimentally infected with *Cl. welchii* continues. The work has been extended to a study of heterologous immune sera and to sera of different species. It has also been found that the inhibiting effect of sera can be abolished by suitable enzyme treatment. This point is being studied in co-operation with the Wellcome Research Laboratories.

Studies on the behaviour of mammalian tissue transplants have continued, using a technique in which the tissues are maintained in the allantoic cavity of the embryonated egg. Earlier observations on systemic effects associated with injury, demonstrated by the effect of serum inoculated into the recipient eggs, are now being applied to a study of antibody-producing tissues.

Work has continued on immunity to *Corynebacterium pyogenes*, particularly on the question of strain specificity in relationship to the immune response. The role of toxin and antitoxin immunity is also being investigated. Antigens produced *in vivo* give protection but so far it has not been possible to produce the protective antigen *in vitro*.

Work on the fractionation of toxic filtrates of *Cl. welchii* by zone electrophoresis in columns has shown that a number of well characterised toxic antigens can be separated satisfactorily from each other. The methods used give good quantitative recoveries and a study is being made of the antigenic composition of various fractions by immune electrophoresis in starch gels. A new type of internally cooled electrophoresis column has been built: this gives a better performance than the apparatus previously used.

Researches on metazoan immunity are continuing using the rat and its parasite *Nippostrongylus muris*. During the year highly inbred rats have been used as well as the outbred hooded rats. Some interesting differences have been observed between the two strains of rats. Routine examinations of other experimental animals in the Institute have been made during the year.

The pathology of "swayback" in lambs produced experimentally by supplementing maternal diets with molybdenum and sulphur has been studied.

Applied Biochemistry. Relationships between diet, bone metabolism and dental disorders of sheep were studied using radiographic, chemical and radio-isotopic techniques, as also were aspects of vitamin D metabolism and assay. "Swayback" in lambs was produced experimentally by supplementing maternal diets with molybdenum and sulphur.

Nutritive variability of commercially available protein concentrates was confirmed; parallel work on predictive laboratory tests and protein hydrolysis preparatory to amino acid analysis continues. The value of amino-acids as supplements to the diet of pigs was studied.

Body composition of table birds was uninfluenced by caloric density of diets, up to high levels. Apparatus to measure body density of pigs was constructed.

Applied Nutrition. In the Applied Nutrition Department studies on the nutrition of the young farm animal continue along the following lines: the effects of enzyme and antibiotic supplements on growth and appetite, comparisons of different levels and sources of dietary protein, the effect of early

weaning on future performance and carcase quality. New projects on the quantitative requirements of the young pig for minerals and on the protein and energy requirements of the calf have commenced.

Financial economies in early weaning rations for pigs have been made by substituting some of the dried skim milk by white fish meal and by reducing the level of antibiotic. Chlortetracycline in the concentrate mixture of early weaned calves increases food intake and growth rate. The reasons for this are being investigated in an experiment using fistulated identical twin calves. Balance experiments have shown that when diets for early weaned calves had a starch equivalent of 68, maximum nitrogen retention is achieved when the crude protein content is about 16.5 per cent.

With bacon pigs further trials are in train to obtain more information on the growth-promoting effects of copper sulphate when added to the feed. Data have been obtained on the relationships between type or breed of pig and level of feeding in the production of high quality carcasses.

It has been found that of the variation in weight which occurs between litters of pigs weaned at eight weeks, only 20 per cent can be attributed to differences in birth weight and 10 per cent to differences in milk consumption but nearly 80 per cent is due to differences in the amount of creep feed consumed.

The addition of the tranquilliser, hydroxyzine hydrochloride, to lamb fattening rations had no significant effect on growth rate but slightly improved carcase quality. It was not possible to detect differences in eating quality between meat derived from hexoestrol-treated and control cattle and sheep.

The relationships between herbage digestibility and N concentration in faeces have been established with a greater degree of precision than hitherto. This has been obtained from continuous digestibility trials with cattle and sheep where fresh herbage of progressively increasing maturity and decreasing digestibility is cut day by day from a single sward. The reliability of estimates of faeces output obtained by employing chromium sesquioxide (Cr_2O_3) as an inert reference substance has been increased by incorporating the Cr_2O_3 in paper and administering the regular doses in this form.

Recent work where these techniques have been employed include experiments to determine the energy cost of grazing to dairy cows, the grazing intake of young beef cattle, and the silage consumption of self-fed store cattle.

Statistics. Workers in other departments have been advised on the design of their experiments, and their results have been analysed and interpreted. Work has also been done on growth data and intelligence test data for adolescents, and on human energy metabolism data.

Duthie Experimental Stock Farm. The nutrition of the breeding ewe during pregnancy and lactation in relation to lamb production continues to be studied. Methods of increasing the production of grass both for grazing and conservation and for the extension of the grazing season are being pursued.

A herd of pigs free from virus pneumonia is in process of establishment. The value of liquid separated milk in replacing fish meal in a cereal diet for pigs was studied.

A.R.C. INSTITUTE OF ANIMAL PHYSIOLOGY

Babraham, Cambridge

Director: J. H. Gaddum, M.A., Sc.D., M.R.C.S., L.R.C.P., F.R.S.

Deputy Director: Sir Alan N. Drury, C.B.E., M.A., M.D., F.R.C.P., F.R.S.

PHYSIOLOGY

Head of Department: Miss C. O. Hebb,
M.A., Ph.D.

K. J. Hill, M.V.Sc., M.R.C.V.S.

K. Krnjevic, M.B., Ch.B., B.Sc., Ph.D.

J. L. Linzell, B.Sc., Ph.D., M.R.C.V.S.

L. E. Mount, M.D., C.M.

J. S. Perry, B.Sc., Ph.D.

I. W. Rowlands, M.Sc., Ph.D.

J. Bligh, B.Sc., Ph.D.

K. F. Hosie, B.Sc., Ph.D., M.R.C.V.S.

BIOCHEMISTRY

Head of Department: Sir Rudolph Peters,
M.C., M.D., F.R.C.P., F.R.S.

R. M. C. Dawson, B.Sc., Ph.D.

V. P. Whittaker, M.A., D.Phil.

D. B. Lindsay, M.A., B.Sc., D.Phil.

J. L. Mangan, M.Sc., Ph.D.

P. F. V. Ward, B.A., B.Sc., D.Phil.

EXPERIMENTAL PATHOLOGY

Head of Department: Sir Alan Drury,
C.B.E., M.A., M.D., F.R.C.P., F.R.S.

A. D. Bangham, M.B., B.S., M.R.C.S., L.R.C.P.

E. J. H. Ford, M.V.Sc., M.R.C.V.S.

A. E. Pierce, M.Sc., Ph.D., F.R.C.V.S., D.V.S.M.

D. C. Hardwick, B.Sc., Ph.D.

Secretary: E. Norris, B.comm.

Librarian: D. W. Butcher, M.A.

Farm Manager: T. M. Fulton

The Institute is devoted to the study of the physiology of normal animals with especial emphasis on sheep, goats, cattle and pigs.

On 31st March, 1959, the scientific and experimental staff numbered fifty-five.

CURRENT WORK

Physiology. Quantitative information has been obtained about the importance of age, weight and environmental temperature in the metabolism of the young pig; the energy saved when little pigs huddle together has been measured. These results have a practical bearing on the problem of the best environment for the survival of newborn pigs and their economically successful rearing, and provide pilot information for a larger programme of research on similar problems, which will be launched when facilities become available. The methods used to measure the loss of embryos inside the sow before birth have been shown to be reliable; some sows habitually lose more embryos than others, and the reasons for this are being studied. Evidence has also been accumulating on the factors which determine the life span of the corpus luteum and its hormonal influence in maintaining pregnancy.

Progress has been made in the study of the reflexes which maintain the body temperature of sheep. It has been shown that panting may occur when the sheep is heated, without any rise in the temperature of the blood going to the brain. This response to heat can thus result from a purely peripheral thermal stimulus; experiments are now being done to discover the thermal receptors for this reflex. Studies on the neurohumoral control of the rumen and the digestive secretions of the gastro-intestinal tract of sheep have been continued successfully. Improvements have been made in the surgical techniques for studying these functions in conscious animals, on which all this work depends.

Progress has been made in developing the technique for studying the production of milk in the isolated udder of a goat—perfused with an artificial substitute for blood. It has been difficult to maintain such preparations for more than an hour or two, but, in recent experiments, such udders have continued for much longer periods to secrete 20–80 per cent of the milk which the same udders had secreted when still attached to the goat. It should now be possible to study the biochemistry of lactation with better control of some of the variables.

The programme of work in neurochemistry and neurophysiology already in progress has this year been supplemented by work in neuropharmacology, the object of which is to study in farm and other domestic animals the pharmacology of synaptic transmission with a view to learning more about the chemical agents which transmit both excitatory and inhibitory processes in the central nervous system.

It is sad to have to record that Dr. G. Fegler, a Principal Scientific Officer of this department, died in September, 1958. Dr. Fegler's work at Babraham, pioneering a new method of blood-flow measurement, and more recently in modifying his technique so as to correlate the blood-flow with the heat production of individual organs, represented a notable achievement.

Experimental Pathology. The absorption of proteins from the gut of newborn calves has been studied by physicochemical methods. It is known that the calf absorbs gamma globulins containing antibodies from colostrum; it has been found that these can be detected both in the blood and urine. The slow formation of gamma globulins in calves deprived of colostrum has been followed.

Work has been continued on methods for studying the properties of the surfaces of cells. Evidence has been obtained, for example, that the dominant group on the surface of a red blood corpuscle is phosphate, whereas that on a polymorphonuclear leucocyte is carboxyl. It is thought that these groups determine the adhesive properties of these cells. The action of lecithinase on a suspension of lecithin has been shown to depend on the electric charge on the particles in the suspension. The interpretation of these results has been confirmed by experiments with a monomolecular layer of lecithin, labelled with radioactive phosphorus and floating on water. The action of the enzyme is followed with a Geiger counter as the phosphorus leaves the surface.

Studies have continued on the levels of activity of a number of enzymes in the blood sera and livers of parturient cattle or sheep. Similar studies have been made on cases of bovine acetonaemia and on ketonaemic sheep. Some work is in progress on the liver lesions produced by dimidium bromide. The occurrence and development of natural iso-haemolysins in young and adult sheep, and their importance in studies on blood group and red cell survival, is being investigated. Observations are also being made on the haptoglobins in sheep sera as genetic markers.

Biochemistry. The South African plant *Dichapetalum cymosum* contains the poisonous substance fluoroacetic acid, which is responsible for the death of cattle. An allied plant, *D. toxicarium*, is also poisonous, but, in this case, the active substance has been shown to be a fluorofatty acid containing eighteen carbons, which has been isolated in large amount by a

new technique, for the study of its chemical structure. This substance causes the death of sheep in three to five days and may well have been responsible for unexplained deaths of cattle in East Africa. These poisons are both converted in the body to fluorocitric acid, which blocks the tricarboxylic acid cycle. This substance has now been isolated and its action on the enzyme aconitase established; an antidote has been discovered which blocks the formation of fluorocitric acid *in vitro*.

Lecithin and other phospholipids are natural antfrothing agents which may be of importance in connection with bloat, and are of importance for very many other reasons. They are not only destroyed, but also formed, by microorganisms in the rumen, and this involves complicated biochemical changes of various kinds. Some of the work on this subject has been done in connection with the Experimental Pathology department and is mentioned above. A method has been devised for estimating all the main phospholipids in a mixture. Monophosphoinositide has attracted particular attention. It activates lecithin so that it is attacked by lecithinase B, but is itself destroyed by several enzymes, two of which have been shown to require activation by calcium salts. Lecithin is converted to glyceryl phosphoryl choline, which is known to be present in high concentrations in semen, and has now been shown to be formed in the epididymis. In collaboration with Dr. Freinkel of Boston, it has now been found that large quantities of free inositol are not only present in the thyroid and the anterior pituitary, but appear to play an active part in the metabolism of these glands.

The metabolism of acetate in sheep is being studied by the continuous infusion of radiocative acetate. Fasting in sheep, which is only effective when the contents of the rumen are temporarily removed, has been shown to be accompanied by the accumulation in the blood not only of ketone bodies, but also of free fatty acids.

Methods have been devised for maintaining oligotrich protozoa from the rumen for 18 months *in vitro*, dividing every 2 days. Work on the localisation of choline esters, and the enzymes which form and destroy them in the brain, continues. Work on the metabolism of proteins in the rumen of cattle on a normal diet has been started.

A.R.C. UNIT OF EMBRYOLOGY

Department of Zoology, University College of North Wales, Bangor, Caerns.

Honorary Director: Professor F. W. Rogers Brambell, B.A., D.Sc., F.R.S.
(Professor of Zoology, University College of North Wales)

Senior Scientific Staff:

W. A. Hemmings, B.A.

R. Halliday, B.Sc., Ph.D.

The principal interest of the Unit has been in the way in which maternal proteins are transmitted to the young animal, either before or after birth. Such maternal proteins include antibodies on which the passive immunity of the young animal depends.

On the 31st March, 1959, the scientific and experimental staff of the Unit numbered four.

CURRENT WORK

Transmission terminates with birth in the rabbit and is mediated, so far as proteins are concerned, by the foetal yolk sac membrane. Work during the year has been concerned mainly with a comparison of the transmission of different fractions of the maternal serum proteins, albumin, α —, β — and γ — globulins, isotopically labelled. A beginning has been made with the problem of how the foetal membrane “recognises” or “handles” the protein molecules by comparing the transmission of whole γ — globulin with various large fragments of γ — globulin molecules, prepared by pepsin or papain digestion and isotopically labelled. The labelled material is injected into the uterine cavity on the maternal side of the barrier and recovered in the serum on the foetal side.

Transmission occurs mainly after birth in the rat by way of the milk and the alimentary tract of the young animal. Research has continued on the transmission of antibodies across the gut of the young rat, both by the use of isotopically labelled serum proteins and of antibodies, which are, in effect, biologically labelled proteins. Particular attention is being paid to a comparison of the transmission of the β —and γ — globulin fractions and to the changes which bring about the termination of transmission at 20 days of age. The endocrinological and enzymological processes concerned appear complex.

Work on experimentally produced haemolytic disease in the mouse continues and a comparison is being made of the syndromes resulting from anti-red cell and anti-leucocyte-platelet sera.

A grant from the Rockefeller Foundation to the College during the year has provided certain equipment which will extend materially the experimental facilities available to the Unit.

A.R.C. UNIT OF MICROBIOLOGY

Department of Microbiology, The University, Sheffield

Honorary Director: Professor S. R. Elsdon, B.A., Ph.D.
(Professor of Microbiology, Sheffield University)

Senior Scientific Officer: J. L. Peel, B.A., Ph.D.

The work on the photometabolism of propionate by *Rhodospirillum rubrum* has been continued. The technique used is based on that developed by Calvin for the study of carbon dioxide fixation in the green plant. There were reasons for believing that the metabolism of propionate involves a preliminary reaction between propionate and carbon dioxide to give succinate and to test this, two types of experiments have been carried out. In the first, the suspension of the organism was illuminated in the presence of labelled propionate ($2\text{-}^{14}\text{C}$ -propionate was used) and unlabelled carbon dioxide; and inactive propionate and labelled carbon dioxide were used in the second. Samples were taken as quickly as possible after mixing and at suitable time intervals thereafter over the next 4 to 8 minutes. The cell contents were extracted and analysed by paper partition chromatography and the radioactive compounds located by radioautography. The labelled compounds were eluted from the chromatograms, identified and degraded

one carbon atom at a time to locate the position of the tracer. So far only the products from the experiments with labelled propionate have been degraded. A kinetic analysis of the process has been made in both types of experiments. The following compounds were found to be labelled in the samples taken 10 seconds after addition of labelled propionate: succinate, fumarate, malate, alanine and aspartic acid. The same compounds along with phosphoglyceric acid were found when the carbon dioxide was labelled. The results are consistent with the hypothesis that propionate reacts with carbon dioxide to yield succinate which is then converted to fumarate, malate and aspartic acid. The labelling of the alanine shows that this compound was not formed directly from the propionate.

A similar series of reactions to the above is known to take place in animal tissues and in this case it has been established that methyl malonate is an intermediate in the conversion of propionate to succinate. So far there is no definite indication that this compound is an intermediate in the *Rhodospirillum rubrum* system but now that the broad outline of the processes has been established a search is being made for methyl malonate.

In the last report some experiments with anaerobic organisms were described which showed that two different organisms, *Saccharomyces cerevisiae* and *Streptococcus faecalis*, grown on the same energy source, glucose, produced identical weights of cells. These experiments also suggested that the weight of cells produced in a culture was proportional to the amount of adenosine triphosphate synthesised by that culture. This work has now been extended in two directions. Firstly, yields of the lactate fermenting organism, *Veillonella gazogenes* have been measured and values obtained similar to those reported for the lactate-fermenting organism *Propionibacterium pentosaceum*. Secondly, a study has been begun of the growth yields of certain aerobic bacteria. The novel feature of these experiments is that the organisms are grown in Warburg monometers. By growing the organisms in this way it is possible to measure the amount of oxygen consumed during growth as well as the dry weight of cells produced. There are reasons for believing that the amount of energy the organism obtains is related to the amount of oxygen consumed and hence by measuring the latter an index of the former is obtained. The results suggest that, with most substrates, the amount of oxygen consumed can be taken as an index of the amount of biologically useful energy the cell obtains. However, when *Pseudomonas fluorescens* was grown upon either sodium benzoate or sodium nicotinate, the ratio:—weight of cells produced/oxygen consumed was lower than that obtained for any other substrate examined. This suggests that, in the case of the two cyclic compounds oxygen consumption cannot be equated with the yield of biologically useful energy. These observations are being followed up.

DAIRYING

THE NATIONAL INSTITUTE FOR RESEARCH IN DAIRYING

Shinfield, Reading, Berks.

* *Director* (till 30th September, 1958):

Professor H. D. Kay, C.B.E., D.Sc., Ph.D., F.R.S.

DAIRY HUSBANDRY

Head of Department: A. S. Foot, M.Sc.

R. Braude, D.Sc., Ph.D., Dipl.Agr.

P. A. Clough, B.Sc.

F. H. Dodd, B.Sc., Ph.D.

C. Line, B.Sc.

K. G. Mitchell, B.Sc., Ph.D., N.D.A.

J. C. Murdoch, B.Sc., Ph.D.

FEEDING AND METABOLISM

Head of Department: C. C. Balch,
B.Sc., Ph.D.

W. H. Broster, B.Sc., Ph.D.

G. S. Pope, B.Sc., D.Phil., A.R.I.C.

J. H. B. Roy, M.A., Ph.D., Dip.Agric.

PHYSIOLOGY

Head of Department: S. J. Folley,
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P. Andrews, B.Sc., Ph.D.

G. K. Benson, B.Sc.

A. T. Cowie, B.Sc., Ph.D., M.R.C.V.S.

H. Gutfreund, Ph.D.

RADIOBIOCHEMISTRY

Head of Department: R. F. Glascock,
B.Sc., Ph.D.

BACTERIOLOGY

Head of Department: A. T. R. Mattick,
B.Sc., Ph.D., M.I.Biol.

C. A. E. Briggs, Ph.D., M.R.C.V.S.

Miss C. M. Cousins, B.Sc.

J. G. Franklin, B.Sc., Ph.D.

Miss E. I. Garvie, B.Sc., Ph.D., N.D.D.

D. J. Jayne-Williams, M.Sc.

F. K. Neave, B.S.A.

B. Reiter, Ing.Agr.

Miss M. E. Sharpe, B.Sc., Ph.D.

CHEMICAL MICROBIOLOGY

Head of Department: N. J. Berridge,
D.Sc., Ph.D.

G. C. Cheeseman, B.Sc., Ph.D., Dip.Bact.

L. A. Mabbitt, B.Sc., Ph.D.

CHEMISTRY

Head of Department: S. J. Rowland,
B.Sc., Ph.D., F.R.I.C.

R. Aschaffenburg, Ph.D.

R. L. J. Lyster, M.A., Ph.D.

J. A. F. Rook, B.Sc., Ph.D., A.R.I.C.

Secretary: H. F. Burgess, M.B.E., A.C.I.S.

PHYSICS

Head of Department: G. W. Scott Blair,
M.A., D.Sc., Ph.D., F.R.I.C., F.Inst.P.

F. A. Glover, B.Sc., A.Inst.P.

J. D. S. Goulden, B.Sc., Ph.D.

L. W. Phipps, B.Sc., A.R.C.S., A.Inst.P.

J. H. Prentice, B.Sc., A.Inst.P.

ENGINEERING

Head of Department: H. S. Hall, B.Sc.
R. T. Budd, B.Sc.

H. Burton, B.Eng., M.Sc., A.M.I.E.E.

J. Hutchinson, B.Sc., A.I.Mech.E.

S. F. Suffolk, B.Sc.

C. C. Thiel, B.Sc., Ph.D.

NUTRITION

Head of Department: S. K. Kon,
D.Sc., Ph.D., F.R.I.C.

Miss M. E. Coates (Mrs. Goodwin),
Ph.D., F.P.S.

J. E. Ford, B.Sc., Ph.D.

Miss M. E. Gregory,

M.Sc.tech., Ph.D., A.R.I.C.

Miss K. M. Henry, D.Sc., Ph.D.,

A.R.C.S.I., F.R.I.C.

J. H. Moore, B.Sc., Ph.D., A.R.I.C.

J. W. G. Porter, M.A., Ph.D.

S. Y. Thompson, D.Sc., Ph.D.

Miss J. Toothill, B.Sc., Ph.D., A.R.I.C.

STATISTICS

Head of Section: C. P. Cox, M.A., F.S.S.

EXPERIMENTAL DAIRY

Miss H. R. Chapman, N.D.D.

DIRECTOR'S LABORATORY

R. H. Smith, B.Sc., Ph.D.

LIAISON UNIT

W. G. Wearmouth, B.Sc., Ph.D.,
A.R.I.C., F.Inst.P., M.Inst.Pkg.

LIBRARY AND INFORMATION

J. A. Irvine, M.A.

C. L. Pinnock, M.A., A.L.A., dipl.Lib.

* Professor R. G. Baskett, O.B.E., M.Sc., F.R.I.C., was appointed Director of the Institute as from 1st August, 1959.

The Institute has been established for 47 years and is concerned with research associated with the wide field of milk production and milk utilisation. Much of the work is of a practical character and is designed to provide dairy farmers with information which will enable them to improve their methods for the economic production of good quality milk. Side by side with this work research of a more fundamental character is carried out in the hope of securing a better understanding of the physiological processes involved in milk production, the specific nutrient requirements of dairy cattle, and the physical, chemical and bacteriological significance of the changes involved in the processing of milk and its products.

Professor H. D. Kay retired on 30th September, 1958, after a directorship of 26 years, and the Deputy Director, Dr. A. T. R. Mattick, became Acting Director.

At 31st March, 1959, the scientific and experimental staff at the Institute numbered ninety-eight.

CURRENT WORK

A detailed account of the results of research work at the Institute is published in the Annual Report, and the following are but brief references to some of the work which is being undertaken.

Dairy Husbandry. For some time data have been collected from commercial farms, and tables have been constructed for use in assessing the performance of milking machine installations with various combinations of numbers of milking units, numbers of operators and routines.

The use of the flail type of forage harvester for high quality hay production has been investigated and high rates of drying have been achieved. So far this has been done at the cost of rather high fractionation losses.

Further work has confirmed the effect of rate of stocking per acre on milk output per acre and the comparatively small effect of the particular grazing method used.

Following earlier observations that relatively high doses of copper added to the diets of growing-fattening pigs results in the improvement of growth rate and the efficiency of feed utilisation, studies have been carried out on various aspects involved in copper supplementation. These have embraced different sources of copper, dose response, copper metabolism, toxicity, together with comparisons with other growth-promoting feed additives, particularly antibiotics.

Feeding and Metabolism. In experiments with young calves, differences in the nutritive value of dried skimmed milk have been shown to arise from variations in heat-treatment of the milk before spray-drying. High temperature or prolonged pre-heating appears to cause denaturation of the milk proteins. Experiments have been in progress in which the production of saliva by cattle has been measured. Production may exceed 100 litres in 24 hours, but the rate of secretion and the composition of the saliva are not closely related to conditions in the rumen. In a joint experiment with the Chemistry Department involving the use of rumen fistulated cows, it has been found that when those volatile acids which are normally produced in the rumen are continuously infused into the rumen of cows receiving

typical winter rations, these infusions have substantial effects on milk yield and composition.

Physiology. Studies on the possible control of anterior pituitary function by the hormones of the neurohypophysis have been extended and further evidence obtained of the ability of oxytocin, under certain conditions, to release prolactin from the anterior pituitary. Mammary development and function in the hypophysectomized goat is also being investigated.

Detailed studies of the biochemical pathways in mammary gland mitochondria are beginning to give useful information about their contribution to the supply of energy and precursors for the synthesis of protein and other milk constituents.

Bacteriology. Work has continued on the examination of practical methods for bottle sterilization and steam at 20 p.s.i. for 10 minutes has been shown to be effective for sterilizing bottles heavily inoculated with resistant spores. A routine using sodium hypochlorite and an alkaline detergent has given satisfactory results for the cleansing of a bulk milk tank under farm conditions.

While control by antibiotic treatment of *Staphylococcus pyogenes* mastitis has not proved possible, a considerable degree of control has been achieved by pasteurizing teat-cup clusters before milking each cow.

The relative activities of many forms of vitamin K have been shown to be the same for a rumen strain of *Fusiformis nigrescens* as for animals.

Chemical Microbiology. An examination of several hundred strains of bacteria has shown that, with the possible exception of a minority of genera, many individual strains can be differentiated and recognized by the patterns produced when extracts from them (which are easy to prepare) are subjected to paper chromatography. The bacteriologist is hereby provided with a technique of strain determination which has marked advantages in speed and sensitivity.

By means of methods which have been developed and are still being improved, it is now possible for the first time to prepare cheese with a controlled microflora and to ascertain the relation, if any, between flora and flavour.

Chemistry. Further progress has been made in the study of hypomagnesaemia and grass tetany in dairy cattle. Investigations of the home-grown foods have shown that the availability, to the dairy cow, of the magnesium of grass at all stages of growth, and of grass silage, hay and kale, is poor in comparison with that of mixed rations containing concentrates.

The alkaline phosphatase of milk, the enzyme of importance in methods for the control of the heat-treatment of milk, has been isolated and purified to a specific activity seven to eight times that previously reported.

Physics. Quantitative studies have been made regarding the coagulation of milk by rennet. The length of the induction period ("coagulation time") and the subsequent rate of setting have been found to be largely independent. The common use of the former only, in cheesemaking practice, is therefore unsatisfactory. The effects of various milk treatments have also been measured.

It has been found that the mechanical properties of junket may in general be described in terms of two elastic and two viscous parameters. The corresponding behaviour of coagulated bovine blood requires only two constants, though the coagulation-time relation is more complex. As with milk, "clotting times" alone give inadequate indications of coagulation.

Differences in the physical properties of bovine cervical mucus in oestrus and pregnancy are found to be paralleled by quantitative differences in one of their components—sialic acid.

Engineering. Many performance tests on dairy equipment for manufacturers have been made during the year, and special scientific apparatus has been designed and manufactured for other departments in the Institute. Work has been undertaken concerning circulation cleaning of milking machines, the design of farm milk tanks, the application of milk meters to bulk collection, the prevention of deposits in heat exchangers, and investigations involving a new method of mechanized cheesemaking.

Nutrition. A rapid microbiological method for the evaluation of protein quality with *Streptococcus zymogenes* has been developed and shows good promise in assessing the effects of processing on milk proteins.

Assays with chicks and rats and microbiological assay showed a loss of 45–70 per cent of vitamin B₆ activity in the preparation of evaporated milk and a further loss of 30 per cent of the remainder after storage in tins for 6 months at room temperature.

Three Gustafsson units have been installed for work with germ-free chicks, the first application being the study of the mode of action of antibiotics in promoting growth.

Radiobiochemistry. Chromatographic analysis of uterine extracts after giving physiological doses of tritium-labelled hexoestrol to ewes is being carried out for the purpose of identifying metabolites.

Plot experiments with grass and turnips grown on ground treated with tritium-labelled hexoestrol show that not more than 1 $\mu\text{g/kg}$ dry matter is absorbed into the plants.

Preliminary experiments with $\mu\text{-}^{13}\text{C}$ and $1\text{-}^{14}\text{C}$ glucose indicate that, whereas the pentose phosphate pathway is of major importance in rat mammary gland slices, it is much less so in sheep udder slices.

Director's Laboratory. Work has continued on the subject of magnesium metabolism in young calves and it has been shown that a milk diet provides adequate magnesium for young calves but not for older calves, mainly because the former absorb much more magnesium in the large intestine. With a more than inadequate magnesium intake, bone plays little part in magnesium homeostasis, but with an adequate intake it buffers the fall in plasma magnesium more and more efficiently as depletion increases.

HANNAH DAIRY RESEARCH INSTITUTE

Kirkhill, Ayr

Director: J. A. B. Smith, C.B.E., D.Sc., Ph.D., F.R.I.C., F.R.S.E.

BACTERIOLOGY

Head of Department:
Constance Higginbottom,
M.Sc., Ph.D., Dip.Bact.
Margaret M. Taylor, B.Sc., Ph.D.,
Dip.Gen.Bact.

BIOCHEMISTRY

Head of Department: E. C. Owen,
B.A., D.Sc., Ph.D.
W. Manson, B.Sc., Ph.D.

GRASS AND DAIRY HUSBANDRY

Head of Department: M. E. Castle,
B.Sc., Ph.D., N.D.A., N.D.D.
D. Reid, B.Sc., Ph.D., M.S.

NUTRITION

Head of Department: K. L. Blaxter,
D.Sc., Ph.D., N.D.A.
D. G. Armstrong, B.Sc., Ph.D., F.R.I.C.

Secretary: Miss M. M. Hughes

PATHOLOGY

Head of Department: P. S. Blackburn,
Ph.D., M.R.C.V.S.

PHYSIOLOGY

Head of Department: J. D. Findlay,
B.Sc., Ph.D.
W. Bianca, Dipl.Ing.Agr., Dr.Sc.Tech.
J. A. McLean, B.Sc.
D. L. Ingram, B.Sc., Ph.D.

TECHNICAL CHEMISTRY

Head of Department: R. Waite,
M.Sc., Ph.D., A.R.I.C.
J. C. D. White, B.Sc., Ph.D.
D. T. Davies, B.Sc., Ph.D.

Librarian: Miss E. T. Davidson

The scientific and experimental officer staff of the Institute at 31st March, 1959 numbered thirty-two.

The main object of the Institute's work is to study a wide variety of biological problems related to the production of milk and a number of technical problems associated with the handling of milk both before and after it leaves the farm. The biological problems include those arising from the production of grass and homegrown feedingstuffs, the nutrition of dairy cattle at all stages of growth and development, energy metabolism in ruminants, milk composition and factors that affect it, the influence of climate on the physiology of cattle, and the eradication and control of mastitis. The technical problems include those associated with the chemical and bacteriological examination of milk and milk products, the proteins of milk and the keeping quality and other properties of dried milk.

CURRENT WORK

Grassland and Dairy Husbandry. One of the main subjects studied under this heading is the efficiency of milk production, the object being to devise and establish methods by which an optimum yield of milk of good quality can be attained with minimum reliance on imported feedingstuffs. This involves much detailed research work of a long-term nature on grassland management and on the conservation and utilization of grass and grassland products. By applying the principles so determined the productivity and profitability of the Institute's farm of 134 acres have been much increased in recent years. In the year now under review the farm produced 41,000 gallons of milk with an average yield per cow in herd of 819 gallons and a yield per acre of just about 300 gallons. The amount of grass dry matter used was almost 60 cwt. per acre and the net amount of feedingstuffs purchased was less than 6 tons.

Recent research on grassland management has included work on the effect of closeness of cutting and of different methods of mowing on herbage yields and composition. In plot experiments with timothy and ryegrass swards the yields obtained with close-cutting ($\frac{1}{2}$ in. from the ground and five cuts in the season) exceeded those obtained with lax-cutting ($2\frac{1}{2}$ in. from the ground and five cuts) by about 20 per cent.

Much work has been done with different types of seed mixtures containing various different strains of grasses and clovers to determine the most suitable types of mixtures for the area in which the Institute is situated. Experiments have continued also on the relative values of ten different strains of lucerne, one of the main objects being to study the practicability of growing this crop in south-west Scotland.

Nutrition. The energy requirements of ruminants for growth, maintenance, pregnancy and lactation is a subject that has been greatly neglected in the past 40 or 50 years largely owing to the very difficult and expensive nature of the work. During the past year, however, the construction of several respiration chambers for sheep and of one large enough to accommodate a cow has been completed, and energy metabolism work with the aid of these chambers is now in progress. The object is to gain as much information as possible on the energy requirements of ruminants and of the ability of different feedingstuffs to meet these requirements.

With the aid of the respiration chambers, work on some of the products of digestion in the ruminant has shown that the energy of glucose and of lactic acid is used more efficiently for fat synthesis than the energy of the lower fatty acids. The sheep chambers have been used also in studies of the effect of grinding and cubing on the nutritive value of a poor quality hay as measured by energy retention and by experiments on its digestibility and its rate of passage through the alimentary tract. Grinding and cubing appeared to have no marked effect on the use the sheep made of the hay for maintenance.

Physiology. During the past year some of the earlier experiments have been concluded and published. They included work on the relationship between respiratory rate and heart rate in the calf subjected to heat stress, the acclimatization of calves to hot dry and hot humid environments, the effect of clipping the coat on various reactions of calves to heat, and work on the histology of the bovine muzzle.

The construction of the new climatic laboratory has been completed. The entire installation has been thoroughly tested and the two climatic rooms it provides are now in full use.

Milk composition. Work on some of the principle constituents of milk and on some of the vitamins it contains has been continued and extended. Very much as the result of the Institute's work and encouragement the Scottish Milk Records Association instituted some time ago a scheme whereby the non-fatty solids content of the bulk milk of all the herds recorded by the Association in Scotland is tested on the farm. The first series of results obtained has been analysed at the Institute with the object of providing valuable information on the composition of milk in Scotland on a scale which has never before been possible.

A series of papers on the work that is being done on protein stability in milk and its chemical composition has now been published. Further work on this subject is in progress.

Bacteriology. In Scotland the coliform test is one of the means by which the hygienic quality of milk is judged, and sometimes milk of very low bacterial count fails to pass the coliform test. A detailed study has been made, therefore, of the associated growth of the coli-aerogenes group and other bacteria in milk. The Institute's work on the growth of spore-forming bacteria in sterilized milk has been continued and some of the findings have been published.

Disease. Mastitis is still one of the greatest single sources of loss in the dairy industry. Work on its eradication and control has continued during the past year and has included research on sub-clinical types of mastitis and their effect on milk yield and composition. The incidence of ketosis in the dairy herd and its prevention and cure have also been investigated, and some work has been done on the occurrence and prevention of hypomagnesaemia in lactating cows.

A printed report for the three years ended 31st March, 1959, has been published by the Institute. It gives an account of the work done in each of the seven departments and ends with a list of the papers published during the three-year period. Copies of the report may be obtained on request.

POULTRY

A.R.C. POULTRY RESEARCH CENTRE

King's Buildings, West Mains Road, Edinburgh, 9

Director: A. W. Greenwood, C.B.E., D.Sc., Ph.D., F.R.S.E.

Assistant Director: J. H. Sang, B.Sc., Ph.D., F.R.S.E.

GENETICS

J. H. Sang, B.Sc., Ph.D., F.R.S.E.

Miss J. S. S. Blyth, B.Sc., Ph.D.

A. G. Cock, M.A.

G. Tebb, B.Sc., Ph.D.

C. F. Pun, M.Sc., Ph.D.

ANIMAL BEHAVIOUR

D. G. M. Wood-Gush, B.Sc., Ph.D.

P. E. Guiton, B.A., D.Phil.

NUTRITION

W. Bolton, D.Sc., F.R.I.C., F.C.S., F.R.S.E.

PHYSIOLOGY

P. E. Lake, B.Sc., Ph.D.

BIOCHEMISTRY

D. J. Bell, M.A., Sc.D., Ph.D., F.R.I.C., F.R.S.E.

W. M. McIndoe, B.Sc., Ph.D.

Secretary: A. B. Totty, B.A.

PATHOLOGY

W. G. Siller, B.Sc., D.vet.Med., M.R.C.V.S.

Librarian: J. B. Coltherd, M.A.

The object of the Centre's work is the study of the biology of the fowl in all its aspects, with particular emphasis on the problems of fundamental importance to the Poultry Industry.

The scientific and experimental staff of the Centre numbered nineteen at the end of March, 1959.

CURRENT WORK

In the previous report, the main aspects of the Centre's work were summarised in the article on Poultry Research in Great Britain. Only selected new or completed projects therefore are described below.

Genetics. In view of the importance of hybrid stock to the Industry use is being made of the Centre's selected lines of Brown Leghorns to examine the problem of hybrid vigour, and particularly, for the study of the behaviour of production characteristics in crosses. Six of the available lines have been crossed in all possible combinations and the behaviour of the progeny determined in pens and in cages. Growth rate and egg size of the hybrids generally fall intermediately between those of their parents. On the other hand, maturity is usually earlier, and production higher, than in the mid-parent. In pens, as judged by survivors production, the best hybrids come from the best parents; but this was not so in cages since, under the particular conditions of this test, neither the best parent nor the best cross then achieved their full potential output. There were also differences between reciprocal crosses particularly with respect to early growth and maturity. In some of the crosses these maternal effects on development are distinguishable as early as 48 or 24 hours of incubation. The parent lines also show differences in pre-hatching mortality, and past records have been analysed to define the pattern of causes of death (kidney deficiency, malpositioning, etc.).

Biochemistry. During the winter of 1958-59 a number of pullets maintained in batteries and in full production developed cage layer fatigue (cage paralysis). This complaint has been found to be somewhat prevalent both here and abroad in commercial flocks maintained in battery cages. About half died within a few hours of detection of the condition while the remainder recovered with hand feeding. These birds showed extensive decalcification of ribs, sternum and skull, and a marked osteoclasia. The plasma alkaline phosphatase was high but blood calcium and phosphate levels were normal. In some cases, there was evidence of hyperoestrogenisation a month after the onset of the condition. Special techniques have been developed for the study of this condition and attempts are being made to reproduce it experimentally.

The biochemistry of the formation of yolk is being studied by examination of yolk precursors in the blood. The relationship has been established of one of these substances, important in fat transport, to the corresponding yolk component. The work is being extended to include a study of the role of the liver in the production of yolk components.

Nutrition. Earlier work showed that the nutritional needs of the young chick were different from those of later, growing stages. The examination of the efficiency of digestion has consequently been extended to include the very young bird. Particular attention is being given to fat and to enzyme supplements in the diets of these young chicks since both are being fed on commercial starter rations for broilers, with the object of improving the growth rate.

The relative efficiency of food conversion has been determined for three of the selected lines of Brown Leghorns having widely different production levels. The *net* efficiency for egg production was found to be the same for each of the lines, whereas their maintenance requirements differed. If this

finding also applies between breeds, as well as within a breed, it follows that *gross* efficiency can be improved by two procedures: either by increasing the total weight of eggs laid in the year, or by developing lighter breeds, which have a lower maintenance requirement, but which lay the same total weight of eggs per year.

Physiology. Studies fundamental to the development of A.I. in poultry continue with investigations of conditions affecting semen preservation *in vitro*. A new simplified suspending medium for spermatozoa has been devised which gives 40–50 per cent fertilising capacity after storage for 48 hours at 2°C. This medium is being used for the development of improved semen diluents by determining the effects on sperm longevity *in vitro* of altered combinations of inorganic constituents and of removal and addition of metabolic substrates. The diluent reported on last year has proved to be a satisfactory extending fluid for turkey semen if the diluted semen is used within half an hour of collection.

Initial trials of the effects of different light regimes on the growth of turkey hens has shown that excessive light under certain circumstances has an adverse effect on subsequent egg laying performance. A rapid onset of egg production can be induced by increased lighting after restricted light treatment (6-hour day), but growth is retarded during the limited lighting.

Pathology. Nephritis is one of the most important diseases in the fowl; it is also of considerable comparative significance in view of its widespread prevalence among mammals. The pathology of the glomerular form in the fowl has been described as also has that of visceral gout which is secondary to pyelonephritis in the bird. A study has also been made of gout in reptiles, and the condition was found to be similar in the two phyla. Attempts are now being made to produce nephritis experimentally, and to follow the resulting changes in blood constituents as well as in the kidney.

Preliminary studies of experimental allergic encephalomyelitis have been completed. Using a technique similar to that employed for mammals, lesions (and occasionally symptoms) can be produced which are not only comparable with those of mammalian experimental allergic encephalomyelitis but which also show certain similarities to spontaneous fowl paralysis.

Behaviour. The examination of both genetic and environmental factors influencing reproductive behaviour of the cock is receiving special attention. Hereditary differences controlling mating frequency, readiness to ejaculate, and volume of ejaculated semen have been analysed, and shown to be interdependent and under genetic control. On the environmental side, it has been found that the stimuli which arouse sexual responses in the adult cockerel are partly determined by the birds social experience during a brief and limited period of its post-hatching life. The influence of this early stage of life—the critical period—is not restricted to sexual patterns, but also affects aggressive responses, fear and, probably, feeding behaviour. This period is therefore of crucial importance to the full understanding of what controls the development of behaviour of the fowl. Work has started on the determination of the physiological processes which determine this phase of behavioural development.

HOUGHTON POULTRY RESEARCH STATION

Houghton, Huntingdon

Director: R. F. Gordon, D.Sc., M.R.C.V.S.

PARASITOLOGY

C. Horton-Smith, Ph.D., D.I.C.

VIROLOGY

J. S. Garside, Ph.D., M.R.C.V.S., D.V.S.M.

BACTERIOLOGY

E. G. Harry, M.Sc., B.Pharm., Ph.C.

PHYSIOLOGY

J. Beattie, M.D., D.Sc.*

NUTRITION AND BIOCHEMISTRY

L. G. Chubb, M.Sc., A.R.I.C.

CLINICAL AND DIAGNOSIS

C. C. Wannop, M.R.C.V.S.

W. M. Goodchild, M.Sc., M.R.C.V.S.

Secretary: P. J. Lane, A.C.I.S.

* Attached worker.

The new laboratory block was completed and occupied in the early spring of 1959 and this, together with the completion of two new Isolation Units, has permitted the expansion of certain aspects of the programme. In the main, research has been directed towards the investigation and control of infectious and parasitic diseases of poultry together with certain studies of problems in nutrition and husbandry bordering on the disease field.

The diagnostic service has continued to extend and whilst keeping the Station in touch with problems in the field has provided material for research.

On 31st March 1959 the scientific and experimental staff at the Station numbered eleven and there was one attached research worker.

CURRENT WORK

Bacteriology. Studies of the emergence of antibiotic-resistant strains of bacteria from the alimentary tracts and tissues of fowls following upon the feeding of chlortetracycline has shown that 30 per cent to 98 per cent of fowls excreted tetracycline-resistant strains of *Escherichia coli* within one week of receiving the antibiotic in concentrations of 25 gm/ton to 400 gm/ton in the diet. The recovery of resistant strains occurred more rapidly from a greater number of birds when the higher level was administered and fluctuated in accordance with the absence or presence of antibiotic in the ration. Once established in a flock, however, resistant strains did not disappear completely even when antibiotic feeding was discontinued. Similar studies using chicks infected with *Salmonella typhimurium* showed that 12 per cent to 36 per cent of chicks excreted tetracycline-resistant strains of this organism when given 100 gm/ton of the antibiotic in the ration. Some 6 per cent to 7 per cent of the chicks continued to excrete resistant strains for as long as 10 weeks after infection.

Following investigations of the pathogenicity to the chick embryo of certain bacteria derived from the hen, the effect on embryonic development of contamination with bacteria of saprophytic origin has been studied. It has been found that certain bacteria commonly found on hay and straw, although incapable of growth or survival at incubation temperature, are capable of producing changes in eggs prior to incubation, which are unfavourable to embryonic development.

Tests on the value of treating shell-contaminated hatching eggs with various antibiotics have shown streptomycin to be the most effective for this purpose.

Chick embryos appear to be adversely affected by formaldehyde fumigation over a longer period than that normally accepted. Prolongation of the sensitive period has been found to occur with eggs from certain flocks and with eggs from all sources when stored before incubation for periods longer than 7-10 days.

A simple method of estimating the formaldehyde content of incubators and fumigating chambers has been evolved by which hatcheries can determine the efficiency of their fumigation procedures.

Parasitology. Different strains of coccidia do not appear to respond equally well to the same chemotherapeutic methods and some compounds which have been reported as effective elsewhere have failed to control laboratory infections of *E. tenella* and *E. necatrix*. As a result, strains of coccidia from different sources are being tested for their relative susceptibility to different anti-coccidials. Since drug resistance has been induced experimentally in a laboratory strain of *E. tenella* it is important to know whether the differences in response of two or more coccidial species to the same drug are due to resistance as a result of exposure or to inherent variations in the susceptibility to the drug of the coccidia themselves. Drugs are therefore now tested as a routine against laboratory strains of 3 or 4 species of coccidia of fowl origin as well as against a strain of turkey coccidium, *E. meleagridis*.

The selective action of different anti-coccidial compounds on 4 species of coccidia has been studied and results published.

Work on the potentiation of the anti-coccidial action of sulphadimidine by pteridine in infections of *E. tenella* and *E. necatrix* has been carried out and the final stages of this investigation will take into account the effect on *E. acervulina* and *E. maxima*, both of which are susceptible to treatment with sulphadimidine.

The nature of the immune response to coccidiosis is being studied. The approach to the problem is by means of (1) surgical, (2) serological and (3) histological techniques.

Investigation of the cytochemistry of the coccidia is continuing.

The life history of *Ascaridia dissimilis* is being traced and certain features of the worm's biology are being investigated.

Virology. The department of Virology only came into existence in March 1959 on completion of the new laboratory wing and as the Station has not been equipped for work on viruses most of the work on this subject exists only in prospect. Studies have commenced, however, on infectious laryngo tracheitis directed to the differential diagnosis of this condition and the possibility of preparing a suitable vaccine. A study of the aetiology and transmission of avian encephalomyelitis is envisaged.

Leucosis and fowl paralysis. Detailed plans have been prepared for the erection of a production unit to provide susceptible lines of stock for experimental work on leucosis and fowl paralyzes, free, as far as can be achieved, from these diseases. Preliminary plans have also been prepared for an experimental unit in which work on these diseases will be pursued.

Nutrition and Biochemistry. The distribution of free amino-acids in the tissues, blood plasma, erythrocytes and urine of the fowl has been studied and work is now in progress on the plasma amino-acid patterns and changes in the plasma amino-nitrogen in fowls in which the liver is the site of different pathological conditions.

The effect of different buffers on the resolution of serum proteins by filter paper electrophoresis has been studied and observations are being made on the changes in serum proteins in fowls infected with *Salmonella gallinarum*. The relationship of the ascorbic acid content of the adrenal glands and of plasma to the susceptibility or resistance of fowls to this infection is being investigated.

The effects of oxytetracycline on the production, fertility and hatchability of eggs of individually caged chicken are being determined. The influence on the growth rate and food conversion of young turkeys of supplementing diets with lysine and methionine is being studied.

Physiology. An animal calorimeter has been designed and built for the purpose of obtaining accurate measurements of the heat production and water loss of birds from day-old to "broiler" stage. A constant-temperature chamber to house the calorimeter has also been designed and erected. The design of the calorimeter is such that any combination of temperature and humidity conditions can be selected and held constant for any period of time. Chickens can be studied either on wire mesh floors or on deep litter and provision has also been made for measurements of the rates of oxygen consumption and of carbon dioxide production to be taken at a later date. The calorimeter can provide data on the effects of various total ventilation rates and of speed of air flow at "bird" level.

AGRICULTURAL ENGINEERING

NATIONAL INSTITUTE OF AGRICULTURAL ENGINEERING

Wrest Park, Silsoe, Bedfordshire

Director: W. H. Cashmore, C.B.E., B.A., N.D.A.

AGRICULTURAL MACHINERY TESTING

Head of Department: D. I. McLaren,
B.Sc.(Agric.), N.D.A.

P. Hebblethwaite, M.S., B.Sc.(Agric.), N.D.A.
R. D. Richardson, B.Sc.(Eng.), A.M.I.Mech.E.

FIELD INVESTIGATION

Head of Department: F. S. Mitchell,
B.Sc.(Agric.)

R. E. Arnold, B.A.(Agric.)
G. Shepperson, B.Sc., Dip.Agric.

GRAIN DRYING

Head of Department: J. Woodforde,
M.I.E.E., A.M.I.Mech.E.

P. E. Berry, M.Sc., A.M.I.Mech.E., A.F.R.Ae.S.
J. B. Holt, M.Sc.

M. G. R. Warner, M.A., A.M.I.E.E.

GLASSHOUSE RESEARCH

Head of Department: L. G. Morris,
B.Sc.(Eng.), A.F.R.Ae.S.

G. A. Carpenter, B.Sc., Dip.Chem.Eng.

Commonwealth Liaison Officer: N. M. Garrard, B.E. (mech.)

Secretary: J. W. Andrews, F.C.I.S.

INSTRUMENTATION

Head of Department: S. W. R. Cox,
B.Sc., A.Inst.P.

MECHANICAL ENGINEERING

Head of Department: H. J. Hamblin, B.A.
P. H. Bailey, B.Sc.(Eng.), A.K.C.
D. E. Howson, B.Sc.
T. C. D. Manby, M.Sc.(Eng.)
H. J. Nation, B.Sc.(Eng.), A.M.I.Mech.E.

HORTICULTURAL ENGINEERING

Head of Department: F. H. Vanstone,
B.Sc., Ph.D., A.Inst.P.
A. G. M. Bean, M.A.(Eng.), A.M.I.Mech.E.
J. B. Byass, M.A.
R. J. Courshee, B.Sc.(Eng.)
J. S. Wolfe, B.A., B.Sc.(Eng.)

SOIL MECHANICS

Head of Department: J. C. Hawkins,
B.Sc.(Agric.), N.D.A.
E. R. Fountaine, B.A., B.Sc.

SURVEY

Head of Department: J. K. W. Slater,
M.A., M.Sc.

Librarian: Miss J. A. Midgley

The function of the Institute is research into and development of agricultural and horticultural machinery. Research and investigations provide basic data for the design and improvement of machinery and also the establishing of new and improved farm techniques. In the course of the work some new machines are developed. The Institute also operates a testing service covering all classes of tractors and implements.

The scientific and experimental staff on 31st March, 1959 numbered one hundred.

CURRENT WORK

Farm Surveys. A small scale investigation into damage to potatoes during the harvesting process was carried out. The main survey was on 'Main Crop Potatoes' in co-operation with the Statistical Department, Rothamsted, and the Potato Marketing Board.

Assistance to the A.R.C. Farm Buildings Unit was continued.

Investigations. Further investigation into the causes of damage to grain during threshing in the field has indicated that a number of factors, including moisture content, drum design, method of presentation of crop to drum and variety, are involved. In some circumstances it is not possible to obtain complete threshing without causing damage which will affect the keeping

qualities. An assembly has been designed to allow for a more detailed study.

In co-operation with the Grassland Research Station, Animal Feeding Trials are being carried out to compare hay made from grass cut at three stages of maturity, and with the hay from each stage made by the normal method, by tripoding and by barn drying. The main haymaking investigation is now concentrated on the baling method. Assisted drying techniques such as the tunnel method and the barn drier are being examined.

A four-year series of experiments on the mechanical harvesting of sugar beet after mechanical thinning was completed. Other sugar beet investigations include the preparation of level seed beds, the possibility of mechanical thinning extending the singling period, and the application of systemic insecticides in bands.

Various factors affecting the growth of potatoes are being examined, including the dimensions of the ridge and weed control, with a view to improving the efficiency of potato harvesting.

Research and Development. The study and measurement of the mechanical properties of soil has continued. For research into soil tilth, six respirators have been set up in the field to measure the oxygen consumption of soils and plant root systems.

Grain research has continued with a study of the principles of counter-flow drying, the drying characteristics of wheat, the cooling of grain stored in silos, oscillating and auger conveyors.

The investigation into the processing of sugar beet seed has included an examination of the 'rubbing' process, and the building of four different types of experimental aspirator.

The ditch cleaner, which was developed for the maintenance of standard British field ditches, is now in limited production.

Experiments with an extrusion process have resulted in a small hydraulically operated experimental cubing machine, suitable for processing farm feeding stuffs.

At the request of the Ministry of Agriculture a humane rabbit trap has been developed and passed to a manufacturer.

Horticulture. Investigations into glasshouse heating have shown that temperature variations can be reduced by modifying the lay-out of the heating pipes. The correlation between early yield of tomatoes and variations of night temperature within the glasshouse has been established and it indicates the possibility of improvements to the normal practice.

Work in conjunction with the National Institute for Research in Dairying on transparent plastics has shown that while glass is opaque to the radiation from plants and soil, polythene in particular is almost entirely transparent.

Work has continued on the artificially illuminated growth cabinet, and the water loss from crops under glass in relation to solar radiation.

Experimental work on fruit spraying has resulted in the building of a prototype tractor-mounted P.T.O. driven spraying machine and it is now being operated in commercial orchards to examine the various factors involved.

A study has been made of the factors involved in the production of spray particles likely to drift, and has indicated steps which will reduce the spray drift by up to 90 per cent of its previous value.

Work on the use of tractors for horticultural crops has included a study of the accuracy of steering and the position of mounted implements.

Other investigations include the design of a machine for lifting flower bulbs when grown on an intensive scale, and an examination of the possibility of reducing the cost of mist propagation by using a more simple sensing element.

Apparatus and Equipment. To improve the efficiency of tractor testing, a 'treadmill' and a tractor test recorder are being developed. Other work to assist N.I.A.E. research includes apparatus for counting and measuring the solid density of grain, mobile weighbridges and a technique for marking seeds with fluorescent tracers.

Overseas. The ridging and planting equipment developed for tied ridge cultivation in the tropics has performed satisfactorily for two seasons on various crops in Uganda. Further work will continue to establish the agricultural value of the system.

Assistance has been given in the development of a vehicle for patrolling red locust grounds in Northern Rhodesia, and a simple rice thresher in Malaya.

Testing Service. The demand for routine testing of tractors, tractor wheels, hydrostatic transmissions, and all classes of machine, has steadily increased. Horticultural equipment is now an important part of this demand. The introduction of 'Series Tests' proved very successful and forage harvesters and dry food mixers have been added to the programme for Britain, and a bush clearing series has been started by the East African Testing Unit.

Steady progress is being made in the development of special measuring apparatus and testing techniques for future testing.

Further information on the work described above may be obtained from the Institute's annual report.

SCOTTISH STATION

Howden, Mid-Calder

Director: W. J. West, B.A., Dip.Agric.

Senior Scientific Staff:

R. G. Clark, B.Sc.(Agric.), M.Sc.(Ag. Eng.)

G. Gilfillan, B.Sc.(Eng.), M.Sc., A.R.T.C., A.M.I.Mech.E.

I. M. Robertson, B.Sc., Ph.D.

Secretary: D. Warne, F.C.C.S.

Tests were carried out under Testing Scheme of the National Institute of Agricultural Engineering.

The scientific and experimental staff of the Station at 31st March, 1959, numbered thirteen.

CURRENT WORK

The behaviour of spring-loaded bar-point plough-shares in stony ground was studied and the optimum strength of spring determined. A method of controlling the front furrow width of a 2-furrow mounted plough when working across slopes was devised. The method, utilising the hydraulic system of the tractor, will be applied to other mounted equipment.

Further attempts were made to devise a simple method of dislodging buried boulders which could then be lifted by a grab on the N.I.A.E. stone hoist. The stone hoist was re-designed to give a greater lifting height and a higher rate of working.

Using a special sieving device an examination was made of the variation in seed size in commercial samples of turnip and swede seed to determine the grades of seed available for precision seeders. Field trials were carried out to compare the singling labour required for swede and turnip crops sown with precision and non-precision seeders and to ascertain the effect on singling labour of using a mechanical thinner. Further development work was done on the Station's mechanical thinner with reciprocating heads.

The rate of drying of hay in field ricks of varying size and its relationship with the weather conditions was studied.

Two varieties of oats and barley, with different grain/straw ratios, were grown for the investigation into the effect of swathing on the capacity of three different combine harvesters. The fifth and final trial to compare the yields obtained by direct combine harvesting, swathing and pick-up harvesting and binding, stooking, stacking and threshing, was completed. Further progress was made in the development of a cheap and efficient aerator for swathed cereals and the design of a swather, based on the results of several years' swathing trials, was started.

The survey of farm grain dryers carried out in 1955-57 indicated the problems that require investigating and to enable this to be done an experimental dryer was designed and built.

The investigation into the damage to potatoes caused by various types of harvesting equipment was continued and was extended, in conjunction with the Plant Pathology Departments of the North of Scotland College of Agriculture and the Department of Agriculture for Scotland, to include a study of the possible relationship between the incidence of gangrene and damage.

Work on the manual separation of potatoes from stones and clods continued and included field trials to compare the output of a 4-man team picking on a complete harvester with that of the team split so that two men made a preliminary separation on the machine and the other two completed the work at the pit. Further attempts were made to devise mechanisms capable of differentiating between potatoes and stones and clods. Two-stage harvesting, in which the lifted potatoes were left to weather in a windrow before being picked-up with a complete harvester, was studied to ascertain whether it eased the separation problem on the harvester. The study of the effect, on the clod content of potato drills at harvest, of the wheels of the tractor used for the inter-row cultivations, was extended (1) by employing winch-operated cultivating tools and (2), by using pre-emergence sprays for controlling weeds, thus eliminating one of the

needs for inter-row cultivations. A haulm-puller was designed and built and given preliminary trials.

The examination of the factors affecting the efficiency of a spool-type potato sorter with variously shaped potatoes was continued. Improvements were made to the machine and to the feeding elevator.

STATISTICS

A.R.C. UNIT OF STATISTICS

University of Aberdeen, Meston Walk, Old Aberdeen

Director: D. J. Finney, M.A., Sc.D., F.R.S., F.R.S.E.

Senior Scientific Officer: M. R. Sampford, M.A., D.Phil.

The Unit provides statistical services for agricultural research in Scotland. In particular, the staff of Agricultural Colleges and Research Institutes are advised on statistical aspects of the planning of their work, and assistance is given with the analysis and interpretation of results. The Unit also undertakes investigations into statistical theory and methodology, especially on problems that arise from questions raised by other Institutes or that are in any way related to the needs of agricultural research. The Unit works in close association with the University Department of Statistics.

On 31st March, 1959, the graduate staff of the Unit numbered five in addition to the Director.

In cooperation with the three Scottish agricultural colleges, the Unit has continued the Survey of Fertilizer Practice in Scotland. The analysis of records from the fourth annual series of six districts is now in progress, and an appreciable proportion of the agricultural land of Scotland has now been covered by the survey. The analysis has been expedited and the range of enquiry increased by assistance from the computer at Rothamsted. A study of the sampling errors of these surveys has been begun, and other types of agricultural survey are likely to be planned soon. Cooperation with the Grassland Committee of the Scottish Agricultural Improvement Council and with various investigations on the constitution of milk organized from the Hannah Dairy Research Institute has continued. Data relating to the effects of environmental factors on plant growth are being examined with a view to constructing mathematical models. The study of the theory of selection, with special reference to procedures suitable for plant breeding, has been continued and a number of useful advances made. The Unit has assisted the A.R.C. Radiobiological Laboratory in the monitoring survey of milk produced in the United Kingdom; the analysis of the first year of sample results should serve as a model for the future development of this survey.

A.R.C. STATISTICS GROUP

School of Agriculture, University of Cambridge

Officer-in-charge: R. C. Campbell, M.A., Ph.D.
(Lecturer in Agriculture (Statistics), University of Cambridge)

The Group was established as a separate entity in January, 1956, and is professionally responsible to Dr. Yates, Head of the Statistics Department at Rothamsted Experimental Station. Close contact is maintained both with the School of Agriculture and the Statistical Laboratory of the Faculty of Mathematics at Cambridge. The Group's local computing facilities are augmented by the use of the automatic calculator at Rothamsted.

On 31st March, 1959, the scientific and experimental staff of the Group numbered three.

The Group gives advice and assistance in the design and analysis of animal experiments. Most use of this service has been made locally by the Unit of Reproductive Physiology and Biochemistry, the Institute of Animal Physiology and the Houghton Poultry Research Station; one member of the Group specialises in work associated with these laboratories. The other main subject dealt with is carcass quality of cattle and pigs; another member of the Group, who is on the Advisory Committee of the National Pig Progeny Testing Board, deals with this work. In addition, the Group designs and analyses the Agricultural Research Council's Co-ordinated Experiments on pigs and is associated with experiments at the Council's Field Station at Compton.

RADIOBIOLOGY

RADIOBIOLOGICAL LABORATORY

Letcombe Regis, Wantage, Berkshire

Director: R. Scott Russell, M.A., M.Sc., Ph.D.

RADIOCHEMISTRY

J. D. Burton, B.Sc., Ph.D., A.R.I.C.
E. R. Mercer, B.Sc.

PLANT PHYSIOLOGY AND SOIL SCIENCE

L. J. Middleton, B.Sc., Ph.D.
Miss H. M. Squire, M.A., Ph.D.

FIELD SURVEYS

F. B. Ellis, B.Sc.(Agric.), Ph.D.

FIELD EXPERIMENTS

G. M. Milbourn, B.Sc.(Agric.), M.Sc.

Secretary: E. A. Tyrer, D.S.C.

The Laboratory was established in 1957 to carry out investigations to assess the entry of radioactive substances into food chains. The work falls into three main sections namely:—The investigation of current levels of radioactive contamination in human diet and other agricultural produce in the United Kingdom; experimental studies to elucidate the behaviour of fission products and related substances in soils and plants; and the provision of advice to the Atomic Energy Authority, the Ministry of Agriculture, Fisheries and Food and the Medical Research Council on these subjects. The Laboratory maintains close contact with the Council's Field Station

at Compton where studies of the veterinary aspects of these problems are carried out.

To provide a permanent home for the Laboratory, the Agricultural Research Council has purchased the Letcombe Manor estate near Wantage, Berkshire. Some accommodation in existing buildings should be available at Letcombe before the end of 1959 and construction of the new laboratories necessary to hold the major part of the staff should start in the winter of 1959-60. Meanwhile the work of the Laboratory is carried out in temporary accommodation provided by the Atomic Energy Authority at Grove, Wantage, at the Agricultural Research Council's Field Station, Compton, Berkshire, at the Medical Research Council's Radiobiological Laboratory at Harwell and the Department of Agriculture, University of Oxford. It is expected that the whole staff of the Laboratory will be transferred to Letcombe early in 1961.

On 31st March, 1959, the scientific and experimental staff of the Laboratory numbered sixteen.

CURRENT WORK

Plant Physiology and Soil Science. The study of the aerial contamination of agricultural crops has been continued, using laboratory spraying equipment. It has been possible to make a preliminary assessment of the extent of contamination of cereal grains, potatoes, cabbages and sugar beet likely to result from a unit deposition of strontium 90 or caesium 137 at various stages of their growth. If strontium 90 is deposited in soluble form after the ears of cereals have emerged it is likely that they will be contaminated ten times more, on a dry-matter basis, than edible leaf vegetables; the contamination of underground storage organs is relatively small. The fraction of caesium 137 recovered from the edible tissues of all crops is considerably greater, because of the greater mobility of this isotope within plants, and because it is transferred to storage organs some ten to twenty times more readily than strontium 90. Investigations are being continued to provide more detailed information both on the situation in the field, and on the mechanism of foliar uptake.

Studies of the aerial contamination of pasture grasses are in progress both on a laboratory scale and by field experiments. A considerably greater fraction of the strontium 90 which has been deposited per unit area of ground is found in the foliage of slow growing hill pastures than in that of typical lowland areas. It appears that a major factor responsible for this is the retention of strontium 90 in the root-mat. Studies are being extended to provide more detailed information on changes with time in the strontium 90 content of established pastures which have been subjected to a single application of radioactive strontium. Comparable studies with caesium 137 have been initiated.

The results of earlier studies on the absorption of radioactive strontium and calcium from soil have shown that the ratio in which these two ions are absorbed by plants is determined by their relative concentrations in solutions with which soils are in equilibrium. It has become apparent, however, that equilibria in which calcium takes part in soil may, under some circumstances, be considerably more complex than was hitherto thought; continuing isotopic exchange can occur for many weeks after soluble labelled

calcium has been added to soils and this results in a continuing decline in the specific activity of the calcium absorbed by plants. The mechanism of this process is under study.

Long-term experiments are in progress in which strontium 90 and caesium 137 have been added to the surface of soil in cylinders approximately one metre in diameter and one metre deep in which grass and annual crops are grown. A representative range of soil types has been used in this work which provides material for the study of the rate at which the availability of both isotopes changes with time.

The importance of obtaining quantitative information on the absorption by plants of radioactive substances of the radium and thorium series has been indicated by reports of appreciable quantities of these materials in various articles of human diet. Arrangements have been made for a preliminary investigation to be carried out.

Field Experiments with Strontium 89. The field experiments in various parts of Southern England which were started in 1956 have been continued. These were undertaken both to determine the extent to which variation in cultivation procedures can reduce the absorption of strontium 90 by plants and to measure the ratio of strontium 90 to calcium in plants which will result from their growth in contaminated soil. It appears that, on a country-wide average, the ratio of strontium 90 to calcium in plants will be approximately one microcurie per gramme of calcium if one millicurie of strontium 90 is incorporated into soil per square metre. If, however, the deposit remains on the soil surface, shallow-rooted crops such as pasture species may show values two to three times higher.

When established pastures are contaminated and subsequently defoliated it is found that the contamination of grass which regenerates after contamination may be up to five times higher than grass newly sown on the same land. The application of lime frequently has a larger effect on the strontium 90 content of established pastures than of newly-grown crops.

These investigations indicate the desirability of deep cultivation if land is contaminated, especially when surface-rooted crops are to be grown. They also show the considerable benefit which would result from re-seeding of contaminated pastures. Work is being continued to obtain more precise information on these questions.

Survey Investigations of Strontium 90 from world-wide fall-out. The results of the first year's survey of strontium 90 in human diet have been published (Agricultural Research Council Radiobiological Laboratory Report No. 1, ARCRL/1). Particular attention has been given to milk since it contributes the major part of the strontium 90 now present in human diet. Samples are collected every two weeks from depots which together handle more than 40 per cent of the country's total production. They are bulked according to a statistical plan devised by the Council's Unit of Statistics, Aberdeen. During 1958 considerable assistance in analytical work was provided by the Atomic Energy Authority since facilities at the Laboratory became available only late in that year. The survey showed that, during 1958 the ratio of strontium 90 to calcium in the average diet of the United Kingdom was approximately six micro-microcuries per gramme of calcium. Surveys in hill areas, where the transfer of strontium 90 into diet was

likely to be greater both on account of greater deposition in rainfall and of agricultural factors, suggested that approximately four times the mean value might be attained.

If present measurements are to be used to predict the probable level in the future contamination of diet from world-wide fall-out, or to guide the planning of safety measures near nuclear reactors, it is of paramount importance to assess the relative importance of the current rate of fall-out and the cumulative total which has so far been deposited. The comparison of the ratio of strontium 89 to strontium 90 in agricultural produce with that in current rainfall provides important information on this question since the shorter half-life of strontium 89 causes the ratio in any sample of fission products to be approximately halved every seven weeks. Such measurements indicate that the mean delay period between the deposition of strontium 90 in fall-out and its appearance in milk during the summer is one to two months. Evidence of the importance of recent deposition in determining the current levels of contamination in green vegetables and in cereals has also been obtained. It is concluded therefore that contamination of diet with strontium 90 depends mainly on the rate of fall-out rather than on the cumulative total now in the soil.

The deposition of strontium 90 from world-wide fall-out in soil and herbage is being investigated at sixteen sites in the United Kingdom. The bones of animals from some localities are also examined.

Investigation of Caesium 137 from world-wide fall-out in human diet. Plans have been made for work on this subject to be begun. The survey will be less extensive than that undertaken for strontium 90.

Joint investigation with the Atomic Energy Authority of Strontium 89 and Strontium 90 in the Windscale area. This investigation has been continued and the results for the first year after the accident are now being assessed.

STATE-AIDED AGRICULTURAL RESEARCH INSTITUTES

at date of report

England and Wales

Rothamsted Experimental Station	...	Harpenden, Herts.
East Malling Research Station	...	Maidstone, Kent.
Grassland Research Institute		Hurley, Maidenhead, Berks.
Agricultural and Horticultural Research Station.		Long Ashton, Bristol
National Vegetable Research Station	...	Wellesbourne, Warwick.
Welsh Plant Breeding Station		Plas Gogerddan, Aberystwyth.
John Innes Horticultural Institution	...	Bayfordbury, Hertford.
Glasshouse Crops Research Institute	...	Rustington, Littlehampton.
Plant Breeding Institute		Trumpington, Cambridge.
National Institute for Research in Dairying.		Shinfield, Reading, Berks.
Foot-and-Mouth Disease Research Institute (Animal Virus Diseases).		Pirbright, Woking, Surrey.
Houghton Poultry Research Station	...	Houghton, Huntingdon.
National Institute of Agricultural Engineering.		Wrest Park, Silsoe, Beds.

Wye College Hop Research Centre ... Ashford, Kent.

Scotland

Macaulay Institute for Soil Research	...	Craigiebuckler, Aberdeen.
Scottish Horticultural Research Institute		Mylnefield, Invergowrie, by Dundee
Scottish Plant Breeding Station	...	Pentlandfield, Roslin, Midlothian.
Rowett Research Institute		Bucksburn, Aberdeen.
Hannah Dairy Research Institute	...	Kirkhill, Ayr.
Animal Diseases Research Association		Moredun Institute, Gilmerton, Edinburgh.
National Institute of Agricultural Engineering Scottish Station.		Howden, Mid-Calder, Midlothian.
Hill Farming Research Organisation	...	48, Palmerston Place, Edinburgh, 12.

AGRICULTURAL RESEARCH COUNCIL INSTITUTES AND UNITS

at date of report

Field Station	...	...	...	...	Compton, Newbury, Berks.
Animal Breeding Research Organisation					H.Q.: 6, South Oswald Road, Edinburgh, 9.
Institute of Animal Physiology	...	...	...	...	Babraham Hall, Babraham, Cambridge.
Poultry Research Centre	...	...	...	...	King's Buildings, West Mains Road, Edinburgh, 9.
Unit of Animal Genetics	...	...	...	...	Department of Animal Genetics, University of Edinburgh, King's Buildings, West Mains Road, Edinburgh, 9.
Unit of Biometrical Genetics	...	...	...	...	Department of Genetics, Birmingham University.
Unit of Embryology	...	...	...	...	Department of Zoology, University College, Bangor.
Unit of Experimental Agronomy			...	...	Department of Agriculture, Oxford University.
Unit of Insect Physiology	...	...	...	...	Department of Zoology, Cambridge University.
Unit of Microbiology	...	...	...	...	Department of Microbiology, Sheffield University.
Unit of Plant Morphogenesis and Nutrition.			and		Rothamsted Experimental Station, Harpenden, Herts.
Unit of Plant Physiology	...	...	...	...	Imperial College of Science and Technology, London, S.W.7.
Radiobiological Laboratory	...	...	...	...	Letcombe Regis, Wantage, Berks.
Unit of Reproductive Physiology and Biochemistry.			and		Moltano Institute of Biology and Parasitology, Cambridge.
Unit of Soil Physics	...	...	...	...	School of Agriculture, Cambridge University.
Unit of Statistics	...	...	...	...	University of Aberdeen, Meston Walk, Old Aberdeen.
Statistics Group	...	...	...	...	School of Agriculture, University of Cambridge.
Systemic Fungicide Unit	...	...	...	...	Wye College, Ashford, Kent.
Virus Research Unit	...	...	...	...	Huntingdon Road, Cambridge.
Ditton Laboratory	...	...	...	...	Larkfield, Maidstone, Kent.
Low Temperature Research Station			...	...	Downing Street, Cambridge.
Pest Infestation Laboratory	...	...	...	...	London Road, Slough, Bucks.

SCIENTIFIC STAFF NOT ATTACHED TO INSTITUTES OR UNITS

PLANT BIOCHEMISTRY

School of Biochemistry, Cambridge

R. Hill, M.A., SC.D., F.R.S.

REPRODUCTION

Molteno Institute of Biology and Parasitology

Mrs. C. L. Mann, M.D., Ph.D.

VITAMIN ASSAYS

*Dunn Nutritional Laboratory
Cambridge*

V. H. Booth, B.A., Ph.D.

MEAT RESEARCH

School of Agriculture, University of Cambridge

R. W. Pomeroy, M.A., Ph.D.

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Professor Alex Robertson, M.A., B.SC., Ph.D., M.R.C.V.S., F.R.I.C., F.R.S.E.
R. Braude, D.SC., Ph.D. (Member and Technical Secretary)

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